DICAL ROOM
RAL LIBRARY
V. OF MICH.

DEC 29 1933

THE JANUARY SCIENTIFIC MONTHLY

EDITED BY J. MCKEEN CATTELL

DISCOVERY AND EARLY HISTORY OF THE POSITIVE ELECTRON. DR. KARL K. DARROW 5
THE TRANSMUTATION OF THE ATOM. LORD RUTHERFORD 15
APES, MEN AND TEETH. PROFESSOR EARNEST A. HOOTON 24
THE RÔLE OF BACTERIA IN THE CYCLE OF LIFE IN THE SEA. PROFESSOR SELMAN A. WAKSMAN 35
MEAT RESEARCH IN THE UNITED STATES. E. W. SHEETS 50
DEFOLIATION ACTIVITIES OF GRAY SQUIRRELS IN AMERICAN ELM TREES. PROFESSOR CARL G. DEUBER 60
THE TENNESSEE VALLEY AUTHORITY. DR. ARTHUR E. MORGAN 64
SCIENCE SERVICE RADIO TALKS:
MEASUREMENTS OF PERSONALITY. PROFESSOR MARK A. MAY 73
POETRY OF THE ROCKS. DR. R. S. BASSLER 76
EXPLORING FOR PLANTS IN THE SOUTHEASTERN STATES. PROFESSOR EDGAR T. WHERRY 80
THE PROGRESS OF SCIENCE:
Award of the Nobel Prizes in Physics to Professors Heisenberg, Schroedinger and Dirac; The Boston Meeting of the American Association for the Advancement of Science 86

THE SCIENCE PRESS
LANCASTER, PA.—GRAND CENTRAL TERMINAL, N. Y. CITY—GARRISON, N. Y.

Yearly Subscription $5.00 Single Copies 50 cents

NEW BOOKS OF SCIENTIFIC INTEREST

To Begin With. RAYMOND PEARL. xiii + 96 pp. $1.50. Knopf.

In this book on books Professor Pearl discusses men and education for graduate students, along with his list of seventy recommended books. The volume is developed from an article which the author contributed to THE SCIENTIFIC MONTHLY.

Nature and Nurture. LANCELOT HOGBEN. 144 pp. $2.75. Norton.

The author attempts to interpret modern methods of research in human genetics in a manner intelligible to readers with little mathematical knowledge, and discusses methods for detecting differences due to heredity and environment.

Clio Medica: Nutrition. GRAHAM LUSK. xi + 142 pp. Illustrated. $1.50. Hoeber.

The author attempts to present in a concise, readable form, a history of nutrition from the gropings of the ancients toward an understanding of the value of food and its effect on various human ills, down to its present modern phase.

Reptiles of the World. RAYMOND L. DITMARS. xx + 321 pp. Illustrated. $5.00. Macmillan.

A survey of crocodilians, lizards, snakes, turtles and tortoises of the eastern and western hemispheres. The author has attempted to make the book interesting to read as well as scientifically accurate.

Textbook of College Physics. C. A. CHANT and E. F. BURTON. xi + 541 pp. Illustrated. $3.25. Holt.

This book endeavors to present a fairly comprehensive view of the subject of physics in a form adapted to mature students who have had little previous training. Some phases such as wave motion and the physics of the atmosphere are given a position of relatively greater importance than usual.

Amateur Talking Pictures and Recording. B. BROWN. vii + 218 pp. Illustrated. $2.25. Pitman.

This book deals with the making of amateur talking pictures in the home. It describes the equipment used in making these pictures, how they are made, and the experiments that are being undertaken for future developments in this field.

Practical Mathematics. G. M. HOBBS, M. MACLENNAN and J. MCKINNEY. ii + 448 pp. American Technical Society.

A book for self-instruction presenting the principles of arithmetic, equations, formulas, mensuration, graphs and logarithms by a "simple step-by-step" method for persons wishing to learn or review practical mathematics.

Animal Biology. ROBERT H. WOLCOTT. xvii + 61[illegible] pp. Illustrated. $3.50. McGraw-Hill.

The author of this college textbook for beginning students in biology limits the morphological material because he feels that the laboratory is the place to study structure. The writer has emphasized the broader aspects of biology throughout the book.

The Book About Animals. (No author given) i + 100 pp. Illustrated. $2.00. Frederick Warne.

This book gives brief descriptions of animals and birds from all parts of the world, accompanied by many drawings and photographs and twelve color plates. It has been written in simple language for children.

Strange Animals and Their Ways. RALPH and FREDERICK DE SOLA. 64 pp. Illustrated. $1.50. Charles Scribner's Sons.

Dr. R. L. Ditmars of the New York Zoological Park has written the foreword to this collection of brief and simple descriptions of "star" animals representing five classes of vertebrates. They are pictured by full-page pen and ink drawings.

Insect Behavior. EVELYN CHEESMAN. vii + 189 pp. Illustrated. $1.60. Ballou.

A non-technical consideration of a number of phases of insect behavior, endeavoring to interpret the forms which activate them. The author discusses the simpler forms as well as the ants and bees.

World Resources and Industries. ERICH W. ZIMMERMAN. xix + 842 pp. Illustrated. $5.00. Harper.

An appraisal of agricultural and industrial resources by a professor of economics at the University of North Carolina. Through his treatise the author desires to promote a better understanding of our civilization and its problems.

Public Health Nursing in Industry. VIOLET N. HODGSON. xx + 249 pp. Illustrated. $1.75. Macmillan.

This book aims to indicate the potential field of public health nursing in commerce, trade and industry and to assist the nurse entering the industrial health field in planning the most effective program possible.

Guide to Modern Thought. C. E. M. JOAD. 268 pp. $1.75. Stokes.

A concise guide for the intelligent reader, showing the latest trends in modern thought along scientific lines. The author is head of the department of philosophy in the University of London.

THE SCIENTIFIC MONTHLY

THE SCIENTIFIC MONTHLY

EDITED BY J. MCKEEN CATTELL

VOLUME XXXVIII
JANUARY TO JUNE

NEW YORK
THE SCIENCE PRESS
1934

Copyright, 1934
THE SCIENCE PRESS

THE SCIENCE PRESS PRINTING COMPANY
LANCASTER, PA.

Geneva
Wahr

THE SCIENTIFIC MONTHLY

JANUARY, 1934

DISCOVERY AND EARLY HISTORY OF THE POSITIVE ELECTRON

By Dr. KARL K. DARROW
BELL TELEPHONE LABORATORIES

NEGATIVE electrons have been known by now for close on forty years. In this brief period they have been found in almost every situation and held accountable for almost all phenomena. It is a certain and familiar fact, attested daily by the working of countless millions of technical devices which depend upon it, that they can exist and travel freely in a rarefied gas or in a vacuum. Metals are believed to be full of freely wandering electrons, circulating past and even through the atoms. Negative electrons are thought to be responsible for almost every emission or absorption or scattering of light. They are a part of every atom-model and therefore one of the elements of every recent physical image of the world.

During all these years of the ubiquity of its negative counterpart, the *positive* electron has been "conspicuous by its absence." For twenty years at least it has been taken almost as a dogma that no such thing exists; it has been taken for granted that positive charge never appears in nature and must never appear in an atom-model, unless it is loaded down with a mass more than a thousand times as great as that of an electron. Two years ago the theorist Dirac was guided by theories of his own to conceive the positive electron, but no one had foreseen the way in which it was eventually found, and no one so far as I know was looking for it. It arrived as a by-product of the study of cosmic rays, thus adding one more instance to the list already long of great discoveries casually made during researches otherwise intended.

In the course of a big program of cosmic-ray research which Millikan had organized, C. D. Anderson was using the expansion-chamber or cloud-chamber of C. T. R. Wilson to observe the paths of ionizing particles belonging to these rays. Millikan and Anderson were not the first to do this. Others had already photographed the long straight tracks which these particles leave behind them (Skobelzyn's is the earliest name to be mentioned in this connection) and had furthermore observed that in a moderate magnetic field these tracks are either very slightly curved or not sensibly curved at all, so that the corpuscles which make them must be very fast. Anderson, however, made two important innovations.

Previously, everybody had set up the expansion-chamber with its axis vertical and its breadth horizontal, which is the most convenient way. Be it remembered that this chamber is a broad short cylinder filled with air or some other gas, its upper end closed by a transparent plate of glass, its lower end by a movable wall, which is the head of a piston. When the piston-head is suddenly pulled back through the proper distance (a matter of careful adjustment) and the gas expands to the proper degree, the moisture in the gas condenses upon whatever ions

there are; and in ideal conditions each droplet of water is the investiture of some ionized atom or molecule, and every ion is clothed in a visible particle of mist. Long lines of these visible particles mark out the paths of all the ionizing particles which have traversed the chamber shortly before the expansion. Now in the commoner kinds of experiment with Wilson's chamber, the ionizing particles proceed from some sort of laboratory source, a piece of radium, for instance, which can easily be set in the same horizontal plane as the rest of the apparatus; and then it is convenient to have the axis of the chamber vertical (Fig. 1), for the rays traverse the entire width of the gas beneath the cover-plate glass. But the ionizing particles of the cosmic rays mostly move in directions close to the vertical, and evidently the traditional orientation is a very poor one for observing these. Anderson accordingly turned the whole apparatus on its side, so that the breadth of the chamber should lie in a vertical plane; and this is now the universal practise in cosmic-ray research. Such was the first of Anderson's innovations; but the second and greater one consisted in fitting into the chamber a leaden plate, of a thickness of several millimeters.

Many of the ionizing particles of the cosmic rays have so great a momentum that they are able to pierce through even such a barrier with no measurable deflection (Fig. 2). Often indeed they are moving so tremendously fast that even in a strong magnetic field their tracks seem perfectly straight on both sides of such a plate.[1] Anderson, however, had a magnetic field exceptional both for strength and for extensiveness, and a chamber of corresponding breadth (the field, of course, is parallel to the axis and perpendicular to the cover-plate of the chamber); and now and then he observed a track which traversed the plate and was more strongly curved on one side thereof than on the other (Fig. 3).

Consider any such a track. The corpuscle which made it must have been

[1] A magnetic field bends the path of a charged particle moving, or having a component of motion, perpendicular to its own direction; the faster the particle, the less the curvature. The undeflected particles of Fig. 2 and similar pictures might conceivably have been uncharged, but from all we know it is extremely unlikely that an uncharged particle would ionize sufficiently many atoms of the gas to make so conspicuous a track.

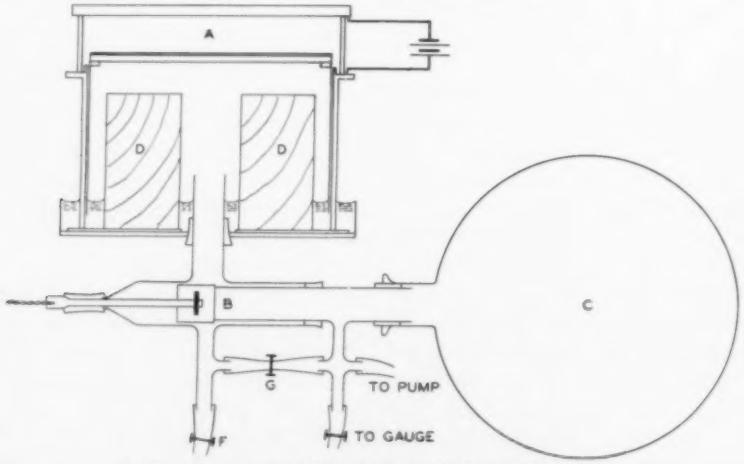


FIG. 1. A WILSON EXPANSION-CHAMBER

(FROM C. T. R. WILSON'S ORIGINAL SKETCH. WHEN THE VALVE B IS OPENED THE AIR BENEATH THE GLASS PLATE UNDER A RUSHES INTO THE EVACUATED BULB C, AND THE PLATE DROPS ONTO THE BLOCKS D, INCREASING THE VOLUME OF A).

FIG. 2. TRACK OF A COSMIC-RAY PARTICLE TRAVERSING TWO LEADEN PLATES EACH 6 MM THICK. (ANDERSON.)

going from the side where the curvature is less and the speed consequently greater, to the side where the curvature is greater and the speed consequently less. Otherwise we should have to assume that the corpuscle had picked up energy—a great deal of energy, tens of millions of electron-volts, indeed—in passing through the lead; and this seems inadmissible. Such a picture therefore fixes the sense in which the corpuscle described the track; and this fixing of the sense is not a trivial matter at all, but of the utmost importance; for with it the observer can tell from the picture (and from his knowledge of the magnetic field) whether the corpuscle was positive or negative, and without it he can not.

On the second of August, 1932, Anderson had a great piece of luck: he operated his expansion-chamber at just the right moment after the passage of a particle, which by this test was proved to be positive. A Wilson chamber, one must always remember, is not continuously at work; quite the contrary: it detects such particles as pass during the one or two hundredths of a second just before an expansion, and then a period of minutes, or at best a large fraction of one minute, must elapse before it can resume. In the course of a year of almost incessant work, Anderson had actually been observing less than half an hour altogether! A Wilson chamber in cosmic-ray research is more like a gambling device than anything else in physics; you wager the value of a photographic plate on each expansion, and nineteen times out of twenty or thereabouts you draw an absolute blank; but on this August day of 1932 Anderson drew the big prize.

He observed, as I said, the track of a particle which was proved to be positive; but this by itself is no sensational statement; there are various familiar kinds of positive corpuscles of much greater mass than electrons—alpha-particles and protons especially—and one must first of all inquire whether Anderson's particle could have been one of these. All these, however, are ruled out by the length and the appearance of the track. First, as to the appearance: As every one knows who has studied cloud-chamber pictures, the tracks of massive particles such as alpha-particles and protons are always much fatter and thicker than those of fast electrons. The massive particles produce many more ions per unit length of path, and therefore many more droplets of condensed water, than do the electrons. The difference is very striking to the eye;

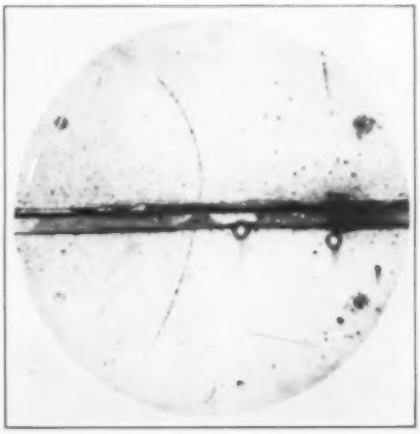


FIG. 3. THE FIRST TRACK OF A POSITIVE ELECTRON EVER RECOGNIZED. (ANDERSON.)

an illustration may be seen in Fig. 7. Now the famous track which Anderson observed was definitely of the thin and slender type, scantily furnished with droplets; and any one of experience would say on looking at it, "Here is the track of an electron!"

This by itself is not conclusive, for according to theory a proton moving with enormous speed—much greater than any yet attained in the laboratory—would likewise produce a thin and scanty track. Here, however, the curvature of the path bears testimony. So fast a proton would not be so much deflected in this magnetic field; and we can state as a fact of experience that if a proton or an alpha-particle in such a field had left behind it a trail of such a curvature, that trail would have been much fatter and thicker than the one which Anderson observed. Not only would it have been thicker, it would also have been much shorter; for the massive particle would have squandered its energy so rapidly in forming ions that its course would have come to an end in five millimeters, whereas the actual path on one side of the plate in Fig. 3 is five centimeters long.

Anderson's particle was therefore much more like an electron, in everything but the sign of its charge, than it was like a proton or an alpha-particle. Now the question arises: How accurately can we estimate its charge and its mass from the length and the appearance of its track? This, as one can readily imagine, is a very intricate theoretical problem. It will always be an important problem, but luckily it is not so urgent as it used to seem; for Thibaud has succeeded in applying one of the classical deflection methods of measuring charge-to-mass ratio, and it is altogether likely that eventually we shall have as accurate a value of this ratio for positive as we do for negative electrons. Thibaud thus far has published only the statement that the two values are of the same order of magnitude; one of his colleagues assured me that the value for positive electrons is almost certainly between one half and twice, and quite certainly between one tenth and ten times, that for the negative electron. This is already a great advance over the previous estimates, and an important result in itself; the ratio for the next lightest of positive particles, the one hitherto supposed the lightest of all, is only .0054 as great as that of electrons.

We now take leave of Anderson's particle, probably the most famous individual corpuscle in the history of physics; one wishes it were preserved in a museum, but of course Anderson could not capture it, and alas, we must perhaps suppose that it no longer exists; for according to many theorists, it must long since have merged with a negative electron and vanished into light. The scene now shifts to the Cavendish Laboratory, where Blackett and Occhialini were also studying cosmic rays with an expansion-chamber lying on its side. They had done what every one at Monte Carlo would like to do; they had contrived not to make any bets, not to wager the price of a single photographic plate, excepting at moments when there was a far better than average chance of drawing a prize. This they achieved by setting up a pair of Geiger counters, one on each side of the cloud-chamber, and a mechanism so contrived that the chamber would expand when and only when both of the counters should react at the same or nearly the same instant. Such a coincidence might mean that a single ionizing particle had passed through both the counters; if so, its track would appear in the cloud-chamber lying between. Or again it might mean that somewhere in the neighborhood there had been a sort of atomic explosion, with ionizing particles hurled in all directions; in which case, some of these might pass through the cloud-chamber itself. In fact they got a number of photographs such as Fig. 4, showing what they call by the well-chosen name of "showers": bursts of many tracks, all radi-

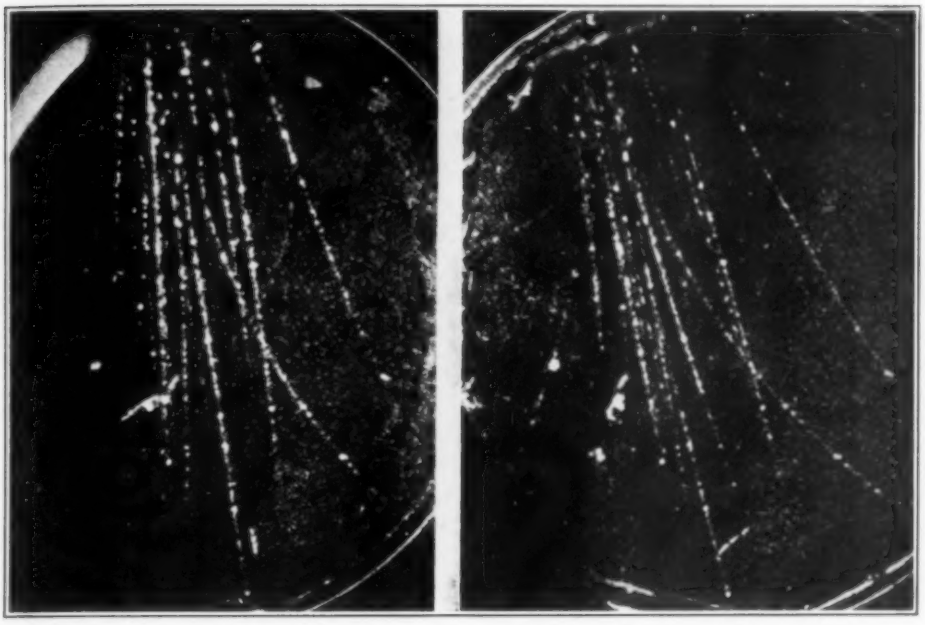


FIG. 4. A COSMIC-RAY "SHOWER" OF SOME 16 TRACKS
PHOTOGRAPHED FROM TWO VIEW-POINTS. THE TWO TRACKS WHICH ARE CONCAVE TO THE RIGHT ARE DUE TO POSITIVE ELECTRONS. (BLACKETT AND OCCHIALINI.)

ating from a single point which generally lies somewhere in the mass of metal surrounding the chamber. There are many interesting features of these showers; but we are here concerned with only one—the occurrence of tracks which have the peculiar aspect and appearance of electron-tracks, and some of which are curved one way and some the other. This might mean that some negative electrons are shooting out from the radiant point and some are shooting in; but it is surely one of the most deep-seated of human convictions that when tracks are seen to diverge from a common point, the objects which made them must have traveled outward and not inward, unless for one which may have provoked the flying-asunder of the rest. Or, as Anderson puts it: It is not likely that such a lot of particles would have an appointment to meet at the same place at the same time! We therefore conclude from these pictures that electrons of both the signs sprang out from these explosions.

Thus far, Pasadena and Cambridge had waited for the cosmic rays to furnish them with positive electrons; but now they began to find out how to produce these at will, and this in importance was not far behind the discovery itself. Chadwick and Blackett and Occhialini were the first to manufacture (if so crude a word may be permitted) the positive electron. Just outside the wall of the Wilson chamber they placed a piece of beryllium exposed to constant bombardment by the alpha-rays of polonium; this, as had been discovered only a little earlier, is a "source" from which both neutrons and high-frequency photons are continually being emitted; I will denote it by the symbol "Po + Be," which is becoming the usage in France. Just inside the wall they put a piece of lead. The glass was no obstacle to the great majority of the neutrons and the photons; many of them impinged on the lead, and at the expansions it was observed that cloud-tracks sprang forth from the metal, and that they had the specific appearance of electron-tracks,

FIG. 5. A COSMIC-RAY SHOWER OF 5 TRACKS, 2 OF POSITIVE AND 3 OF NEGATIVE ELECTRONS. (ANDERSON.)

and that some of them were curved one way in the magnetic field and some the other. Just the same thing was shortly thereafter observed by Meitner and Philipp in Dahlem, except that they had the source "Po + Be" within the chamber itself enclosed in a capsule of brass. At the expansions they found electron-tracks arising from the capsule, and some of these were curved one way and some the other.

The pictures thus imply that electrons of both signs are expelled from lead or brass by the rays of the "Po + Be" source. Still, it may be contended that what appear to be tracks of positives coming forth from the metal are really tracks of negatives coming from the far side of the chamber or out of the gas itself and plunging into the metal. In view of the other evidence for positive electrons, this probably seems a far-fetched idea; but there is nothing intrinsically incredible about it, and if there were no other evidence, it would be the more natural and acceptable idea. Indeed it appears to have delayed the recognition of the positive electron by months and to have shifted the discovery across the sea. As early as the spring of 1932, M. F. Joliot and Mme. Joliot (Irene Curie), in the Institut du Radium in Paris, were admitting the rays of Po + Be into expansion-chambers, and photographing the tracks which occurred in the gas; and they observed and remarked that some of these appeared to be the tracks of electrons traveling backwards toward the source! That worried them a good deal, and they invented a two-stage process to explain it, whereby neutrons shooting forward from the source should cause atoms of the gas to send out photons, and these photons should be absorbed in other atoms and expel the retrograde electrons. It now seems quite beyond doubt that Curie and Joliot were observing forward-moving positive electrons instead of backward-moving negatives, and indeed they helped to prove it. Later on, for instance, they repeated the experiment of Chadwick and his colleagues which I have been describing, first with a piece of lead exposed to the rays of Po + Be, and then with an exactly similar piece of aluminium. Nothing whatever had been changed about the chamber, except the nature of the metal, but there were very many more of these peculiar tracks proceeding from the metal when it was lead than when it was aluminium. The most

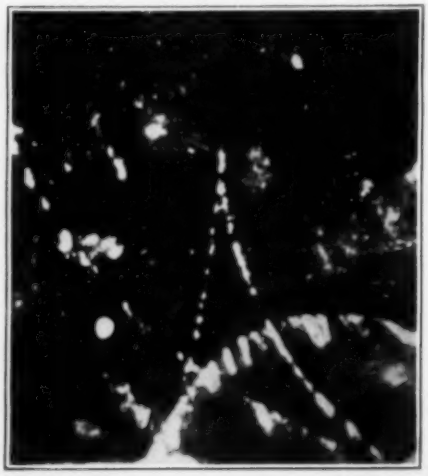


FIG. 6. TRACKS OF AN ELECTRON-PAIR ARISING IN ARGON EXPOSED TO GAMMA-RAYS, AND PROBABLY CREATED FROM A PHOTON AT ITS APPROACH TO AN ARGON NUCLEUS. (CURIE AND JOLIOT.)

conclusive evidence, however, had earlier been supplied by the physicists of Cambridge: they adopted Anderson's test, setting a thin sheet of metal close behind the lead where it would intercept the tracks; and several times it was observed that where a track passed through the sheet, its curvature was greater on the far side, showing that the corpuscle which made it had indeed proceeded from the lead.

Taking it now for proved that there are such things as positive electrons, let us examine what more is known or conjectured about them.

A question comes up immediately: In this mixture of neutrons and photons from the Po + Be source which ejects the positive electrons from lead, are the neutrons or the photons responsible? One might prefer the neutrons, on the plausible ground that these are newly discovered particles of which almost anything is still believable, while photons have been known for quite a while without any one observing that they are able to engender positive electrons; but apparently one would be wrong. Curie and Joliot found that if they inserted metal screens between the Po + Be source and the leaden block, the number of positive electrons evoked from the lead was reduced not at all in the proportion in which the neutrons were cut off by the screen, but more nearly in the proportion in which the photons were cut off; and this certainly settles that the last-named are chiefly responsible, if not indeed altogether. There is another fact which may be relevant to the issue, and anyhow is of the first importance in itself. It is possible to generate positive electrons by streams of gamma-rays—high-energy photons—coming from radioactive bodies which do not emit any detectable number of neutrons at all.

Here are the data in a brief table, in which the first column contains the names of various sources of gamma-rays; the second, the energy-values (in millions of electron-volts) of the individual photons of these rays; the third, the names of various metals; the fourth, the number of positive electrons per hundred negatives, ejected from these metals by these gamma-rays; and the fifth, the authorities:

Po + Be	5	uranium	40	Joliots
		lead	30	Joliots
		lead	35	Chadwick
		copper	18	Joliots
		aluminum	5	Joliots
ThC″	2.6	lead	8	Joliots
		lead	4	Chadwick
Ra(B + C)	1.0–2.2	lead	3	Grinberg
Po	0.85	lead	0	Meitner-Philipp

The percentages in the fourth column give at the moment our best available notion about the relative plentifulness of the positive electrons, ejected from the several metals by the several kinds of rays.[2] One would prefer to have the

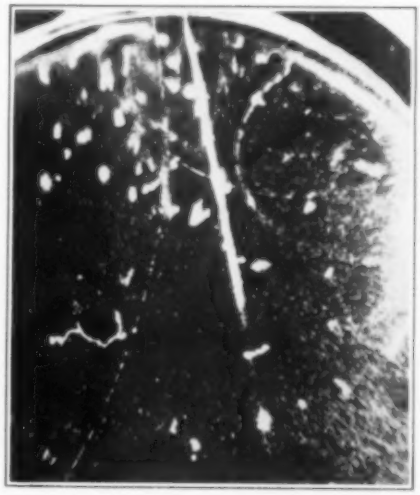


FIG. 7. TRACK OF A 3,000,000-VOLT POSITIVE ELECTRON SPRINGING FROM ALUMINIUM EXPOSED TO ALPHA-RAYS (THE LONG TRACK CONCAVE TO THE RIGHT; THE THICK TRACK IS THAT OF A PROTON, THE OTHERS OF NEGATIVE ELECTRONS. (JOLIOT AND CURIE.)

[2] Meitner and Philipp give an estimate of one third for the proportion of positives to negatives when brass is exposed to (Po + Be); this does not agree well with the value quoted for copper, and they qualify it as a mere

total number of positives per unit intensity of the infalling rays, but that is not available at present—perhaps because of the difficulty of measuring these intensities. It must be kept in mind that the data usually consist in observations of a few hundred or even a few dozen cloud-tracks, so that the accuracy of these percentages can not be great.

We note, then, that with lead the percentage of positive electrons goes up rapidly with increasing photon-energy, and that with photons of five-million-electron-volt energy the percentage goes up rapidly with the nuclear mass of the bombarded atoms. Both of these rules are in harmony with a current theory of the generation of positive electrons. So are other facts of experience; but before stating them, I will state the central idea of the theory, which is simple and spectacular. A positive electron is supposed to come into being by virtue of a transmutation more drastic and amazing than any hitherto effected or imagined: *it is supposed that a photon transmutes itself into a pair of electrons, one of each sign.*

Such a transmutation—if it happens—leaves the net charge of the universe unchanged. If in addition it is to leave the net energy of the universe unaltered, we must invoke the principle of the equivalence of energy and mass: Einstein's relation,

$$E = mc^2$$

where E stands for energy and m for mass and c for the speed of light *in vacuo*. The masses of two electrons at rest, when translated into units of energy according to Einstein's relation, amount to about one million electron-volts ($1.02 \cdot 10^6$ is more nearly right, but the even million is a good round number perfectly satisfactory for these data). The residue of the energy of the photon—its original energy, minus this million—then remains over; it might go into kinetic energy of the electrons, or into a new photon, or divide itself between these forms. Here are testable consequences of the theory. If this central idea is right, then positive and negative electrons should spring forth in pairs, and the energy of each electron-pair, and *a fortiori* that of any positive electron by itself, should never come within one million volts of the energy of the primary photon.

Now it is indeed a fact that positive electrons are often paired with negatives, in the sense that one of each sign appears to spring from a single point on the irradiated metal. Fig. 6 is a wonderful photograph in which a pair is seen to start from a point in the gas of the chamber. There are always some positives which are apparently unpaired; but one can explain this away by saying that probably the associated negative got caught in the metal. There is also always an excess of negatives, as the table has shown; but one can always say that this excess consists of electrons expelled from the atoms by the photons in ordinary collisions. Finally, it is an empirical rule that the kinetic energy of an electron-pair or of an isolated positive never comes within a million volts of that of the primary photons. Everybody who has been producing positive electrons has been looking for exceptions to that rule, and thus far, I believe, no unimpeachable exception has been found. Thus, Anderson and Neddermeyer observed twenty-two pairs and thirteen isolated positives, and found only one case of a pair having more than the proper maximum energy; and this, as they say, might have been a case of two independent electrons happening to start from points close together. Another corollary of the theory is that photons of energy less than one million electron-volts ought not to produce any positives at all; and this is borne out by the nega-

estimate (*ueberschlagsmässige Rechnung*). Anderson finds as many positives as negatives among the ionizing particles of the cosmic rays, which perhaps is to be taken as meaning that these are due to photons of very high energy-values indeed.

tive result obtained with the gamma-rays of polonium.

In this imagined process of transmutation, charge is conserved and energy is conserved, in conformity with two familiar principles. There is yet another principle of conservation, older than either; it is Newton's third law, that the total momentum of the world ought to remain invariable. Now if we attempt to apply this principle to the pictured process, we reach a disconcerting conclusion: if a photon in the depths of space should convert itself spontaneously into two electrons, momentum and energy could not possibly both be conserved![3] This seems at first to impair the theory greatly, as it is not without the greatest reluctance that physicists would forego the conservation of momentum. We recall, however, that positive electrons have not been shown to spring into existence in the depths of space, but only where a beam of photons is traversing a sheet of matter. This suggests that the nucleus of some atom enters into the process, to the extent of receiving enough momentum to balance the budget; and inversely that the process can not occur unless there is a near-by atom available to serve this purpose. In the fully developed theory, indeed, an atom is always introduced to play this rôle.

There is another set of data with which the theory attempts to cope, and this pertains to the absorption of high-frequency photons by heavy elements. There are three well-known kinds of adventure which may befall a photon when it dives into a metal. It may simply be deflected, without sensible change of energy; or it may have what is known as a Compton collision with a nearly free electron, and be deflected with a loss of energy; or it may be utterly swallowed up in an atom, and expel a photoelectron. If a beam of x-rays or gamma-rays is sent through a sheet of metal, any photon which undergoes any one of these adventures is removed from the beam; and accordingly it may be said that there are three modes of absorption. Now quite a good deal is known about these three, and it can safely be said that for most elements and most x-rays or gamma-rays, they constitute all the absorption which occurs. However, it was discovered, three or four or five years ago, that with very heavy elements and very high-frequency gamma-rays, the total absorption is greater than can be ascribed to these three modes put together. There must consequently be an extra mode; and people have been calling it "nuclear absorption," on the general ground that the nucleus must be to blame for anything that we do not fully understand.[4]

It has lately occurred to several physicists that this extra absorption is simply that of the photons which convert themselves into electron-pairs. This idea is in general agreement with the facts that the extra absorption increases rapidly with frequency of gamma-rays and atomic weight of metal, which, as I have just been saying, is also the rule for the production of positive electrons. Moreover, it agrees with the fact that no one has yet observed this additional absorption with gamma-rays of lesser energy than one million electron-volts. Indeed, there is a very recent and interesting note by a physicist, Gentner, at Paris, who plots an experimental curve of extra absorption *versus* frequency and then extrapolates it, and finds that the extrapolated curve comes down to zero at just about the frequency where the energy of

[3] If we postulate both conservation of energy and conservation of momentum, it follows (the reckoning is easy) that the speed of one at least of the electrons is superior to that of light, which is contrary to the doctrine of relativity on which the calculation is based, and therefore a *reductio ad absurdum*.

[4] With this extra absorption there goes an extra "scattering" or emission of gamma-rays from the metal, and it appears that some of these have the proper energy to be attributed to a process which is the reverse of the one already described—that is to say, the coalescence of a pair of electrons of opposite sign into a corpuscle of light. Not all the measurements, however, are concordant.

the photon amounts to one million electron-volts—just the minimum amount, that is to say, which should suffice to create an electron-pair. There are further confirmations. Oppenheimer and Plesset have been working out the quantum-mechanical theory of this imagined process of the transmutation of light into electron-pairs, and have published a brief account of its conclusions, in the course of which they say: "Numerical calculation for the case of the gamma-rays of thorium C" . . . gives an excess absorption of about 25 per cent. of the Klein-Nishina [*i.e.*, the Compton-collision] absorption in lead and 15 per cent. in tin, in excellent agreement with experiment."

Well! when a theorist of the rank of Oppenheimer speaks of "excellent agreement with experiment" it is necessary to take the theory seriously, and this is a theory of the first importance. Here we witness, it may be, the disappearance of the last apparent barrier in physics: the barrier which seemed to separate the substance of electricity and matter from the substance of light. We have long been accustomed to the idea, and perhaps we shall soon be accustomed to the fact, of every sort of transmutation among the divers elements of matter; but the idea of transmutation between matter and light is one which will require years to realize in all its implications. Perhaps, however, it would be well to be a little cautious, awaiting the results of further tests which the quantum-mechanical theory invites[5]; not yet is it safe to discard the idea that these electrons, of whichever sign, may simply have been expelled by the photons from atom-nuclei where they have previously been existing. I therefore bring this story to its end not with a paean of triumph to the theory, but with a description of the latest and most potent method of producing positive electrons, discovered by the Joliots hardly more than half a year ago.

What the Joliots observed was the emission of positive electrons from a leaf of aluminium foil, exposed to the bombardment of alpha-particles from polonium. Later on they observed the like effect when targets of boron and of beryllium were substituted for the aluminium. (It is easy to confuse this observation with the earlier one, in which the rays emitted by the bombarded beryllium were found to evoke positive electrons from a second piece of metal; but in this later work the positives which were observed came forth from the beryllium itself). It may well be an accompaniment of transmutation, for the alpha-particles which cause it likewise possess the power of transmuting all three metals. It is not a universal effect, for it is not observed when lithium is substituted for the aluminium (this proving incidentally that the positives are not from the polonium itself). From aluminium the number of positives emitted is of the order of one to every couple of million of incident alpha-corpuscles; and several months ago Joliot composed a source capable of producing thirty thousand positive electrons to the second. Somewhat later, Thibaud got streams of positive electrons from capsules of radioactive salts enclosed in silver or lead—streams sufficiently strong to cause a fluorescent screen to shine with a light bright enough to be photographed. By comparison with the mighty torrents of negative electrons which flow in any technical vacuum tube, these feeble currents may seem trivial. That, however, is not the proper standard of comparison. One should rather say that in the autumn of 1932 positive electrons were being observed at the rate of three or four a year, and already in the summer of 1933 this rate had been enhanced to thirty thousand in the second.

[5] Thus, the theory predicts the distribution-in-direction of the electrons created by the photons, and the division of the kinetic energy between the positive and negative members of a pair; and also (according to Furry and Carlson) it predicts that electrons having kinetic energy greater than a million electron-volts should be found able to create new electron-pairs.

THE TRANSMUTATION OF THE ATOM[1]

By LORD RUTHERFORD

CAVENDISH PROFESSOR OF EXPERIMENTAL PHYSICS, CAMBRIDGE UNIVERSITY; CHAIRMAN OF THE ADVISORY COUNCIL, DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

THE possibility of the transmutation of one kind of matter into another has always exerted a strong fascination on the human mind since the early days of science. During the past thirty years, I have been actively engaged in investigations on various aspects of this question, and I shall try to give you here a brief account of the essential nature of the problem of transmutation and of the methods that have been devised to extend our knowledge. It is a problem that is attracting much attention in the scientific world to-day, and during the last decade there has been a vigorous and sustained attack on it. Experiments, some on a large and costly scale, are now being carried out in many laboratories throughout the world to advance our knowledge.

The first successful experiments in transmutation are comparatively recent, dating back to the year 1919, but in a sense the problem is a very old one and has been the subject of much thought and investigation from the time when science was in its infancy. You have all heard of the alchemists, who were in fact the first chemical investigators, and the search for a substance called the philosopher's stone whereby it was hoped one element could be changed into another. Looking back from the standpoint of our knowledge to-day, we see that there was no hope of success in this quest with the limited laboratory appliances and methods available in those days, and that the experimental evidence brought forward in its support was of a very doubtful and meager character. However, the persistence of this idea through the centuries was mainly due to a philosophical conception of the nature of matter, based on the writings of Aristotle, which had a very great influence on the outlook of the intellectual world in the Middle Ages. According to Aristotle, all matter consisted of a fundamental substance, primordial matter, together with a mixture of the four elements called earth, air, fire and water. One substance differed from another only in the relative combination of these hypothetical elements. On these views, it appeared almost self-evident that one substance could be changed into another if only a suitable method could be found to alter the amount of one or more of these constituents. Naturally, the hope of changing the base metals into the noble element gold assumed a prominent place, and from time to time men arose who claimed that they had discovered the secret of changing copper, lead or other metals into gold. In times of monetary stress, these alchemists were often employed by rulers to restore the finances of the state by making gold. They often succeeded in making a substance that had the appearance of gold, but in general the net result of their experiments was a debasement of the coinage. Even after the possibility of producing transmutation by ordinary laboratory methods had long been exploded, the old ideas persisted in the general mind, so that even to-day impostors or deluded men occasionally appear who claim to have a recipe for making gold, but the only gold they make is extracted from the pockets of their credulous supporters. The poverty

[1] A National Lecture broadcast by the British Broadcasting Corporation on October 11, and published in *The Listener*, its official journal.

of imagination of this class of charlatan is shown by the fact that they have not at once claimed to produce instead of gold the more rare and costly elements like platinum and radium.

The great work of the chemists of the nineteenth century had shown that matter could be resolved into eighty or more distinct elements, and that the atoms composing each of these elements appeared to be indestructible and unchangeable under the action of the physical and chemical forces at their command. The ancient notion of transmutation proved impossible to realize until new and more powerful methods were available. At the same time it became clear from general chemical evidence, such as is embodied in the Periodic Table of the elements, that the atoms of the elements are not unrelated but must possess in some respects very similar structures. This idea received strong support from the fundamental discovery of the electron in 1897, mainly due to the work of Sir J. J. Thomson. The electron, which carried a negative charge of electricity, was found to have a minute mass—only about 1/1840 of the mass of the lightest atom hydrogen—and to be a constituent of all atoms. One or more of these light electrons could be struck out of the atom either by the action of swift particles or by ultraviolet radiation or x-rays. The resulting atom acquired a positive charge and had different properties from the neutral uncharged atom. The change of properties was, however, only momentary, for in a very short interval another electron fell into the atom and filled the vacant place, and the atom was restored to its original state. General evidence indicates that it is impossible to cause a *lasting* transmutation of the atom by removing or adding electrons to the outside of the atom. Whatever effect is produced by such action is only of a fleeting character and has no permanent effect on the structure of the atom.

The discovery of the radioactivity of uranium by Becquerel in 1896 was another landmark in the history of our subject. The experiments of Rutherford and Soddy in 1903 showed clearly that radioactivity was a direct manifestation of atomic instability. It was shown that occasionally an atom broke up with explosive violence, hurling out with great swiftness either a massive particle called the α-particle, or a swift electron of light mass called the β-particle. As a consequence of this explosion, the residual atom had entirely different physical and chemical properties from the parent atom. It was found that the successive transformations of the two elements uranium and thorium gave rise to thirty or more new elements which had radioactive properties. Radium is the best-known example of these many elements which originate from the successive transformations of the element uranium. The then rare gas helium was found by Ramsay and Soddy to be generated by the transformation of the radium atoms, and we now know that this helium arises from the α-particles, which are charged helium atoms expelled from the exploding atom. The study of the swift α- and β-particles and the pentrating x-rays brought out clearly the extraordinary intensity of these atomic explosions, in which energy was emitted of the order of one million times that generated by a combination of two atoms in the most violent explosive known.

This transformation of the radioactive atoms is spontaneous and uncontrollable; neither extremes of heat or cold have any effect on the rate of transformation or on the energy of the expelled particles. At the moment, no definite explanation can be given why the atoms of uranium break up. We have to regard their transformation as a natural process which is governed by the laws of chance. This property of spontaneous transmutation is most strongly shown by the two heaviest known ele-

ments, uranium and thorium, and the radioactive elements which arise from them. Only three other elements have shown this property, and then only to a minute degree compared with uranium or thorium. All the rest of the elements appear to be permanently stable under normal conditions on the surface of our earth; it seems, therefore, that the idea of the immutability of the elements is true under normal conditions for the great majority of our elements.

A further attack on this problem had to await a better understanding of the essential structure of all atoms. It is now clear that all the atoms of the elements are in a sense electrical structures built on the same general pattern. At the center of each atom is a minute but massive nucleus which has a resultant charge of so many units of positive electricity varying from 1 to 92 for the various atoms. At a distance from the nucleus is a distribution of negative electrons in whirling motion, whose number is equal to the number of positive charges carried by the nucleus. It must be borne in mind that the radius of the nucleus, supposed spherical, is extremely minute and in general less than one ten-thousandth part of the radius of the atom as a whole. Yet this diminutive nucleus not only contains nearly the whole mass of the atom, but through its nuclear charge controls the number and motions of the external or planetary electrons, as they have been termed from analogy with our solar system. Since the ordinary physical and chemical properties of an element are determined by the charge on the nucleus and not by its mass, the atoms of a given element may not be all identical in mass or weight, although they must have an identical charge on each nucleus. We now know, largely through the work of Aston, that most of the ordinary elements are composed of a mixture of atoms of different masses called isotopes. For example, the atoms of the light element lithium—which, we shall show later, can be disintegrated by certain agencies—consist of two isotopes, of masses 6 and 7 times the mass of the hydrogen atom, the isotope of mass 7 being more abundant. We shall see that this isotopic constitution of many elements has to be taken into account in interpreting the types of transformation that can be effected. For example, while one isotope may be readily transmuted, the other isotope may be either unaffected or transformed in a different way.

The broad features of the constitution of all atoms are now well established. As a result of the splendid work of Bohr and those who have followed him, we are able to understand the arrangement and motions of the planetary electrons and the way in which light or x-rays are emitted when the atom is disturbed. Unfortunately, we have much less information about the constitution of the minute central nucleus. We know the value of the nuclear charge and the mass of each atom, but we have no precise information on the nature and arrangement of the particles composing it. Until a year or so ago, it was generally supposed that the nucleus of an atom was ultimately composed of two electrical units, the negative electrons of small mass and the positively charged protons of mass 1. At the same time it became clear that secondary units were also present and that the helium nucleus of mass 4—the α-particle—played a prominent part. Recently, however, we have had to extend our views, for undoubted evidence has been obtained of the existence of a new type of particle called the neutron which has a mass about 1 but no electrical charge. At the same time, the discovery this year of what is believed to be the positive electron of light mass—the counterpart of the negative electron—has complicated the problem. However, we may, I think, assume with some confidence that the nucleus of a heavy atom is in general composed of a large

number of particles, some charged like the α-particle and proton, and others, like the neutron, electrically neutral. These are held together by powerful forces in an extraordinarily minute volume and form a very stable structure. We have, however, little to guide us in seeking a more detailed knowledge of the number, arrangements and motions of these constituent particles.

In order to transmute one atom into another, it appears essential to alter the charge on the nucleus. This can be done in imagination by adding another charged particle, say a proton or α-particle, to the nucleus, or removing a charged particle from it. We must, however, bear in mind that the nucleus is a strongly guarded structure held firmly together by strong attractive forces. In order to disrupt a nucleus, it thus seemed likely that very intense forces must be brought to bear directly upon it. One method of accomplishing this is to bombard the nucleus with very swift particles. Now the α-particle, which is spontaneously ejected from radium, is one of the most energetic particles known to science. It was recognized that if a stream of swift α-particles fell on matter, there was a small chance that one out of a great number might have an almost head-on collision with a nucleus. Under these conditions it must approach very near to it before it was turned back by the strong repulsive forces due to the electric charges on the two particles. It must be emphasized that the close collision of an α-particle with a nucleus involves the setting up of gigantic forces between the two nuclei concerned. In the case of light atoms where the nuclear charge is small, calculation indicated that the colliding α-particle, if it did not enter the struck nucleus, must at least approach sufficiently near to distort greatly its electrical structure. Under such disturbing forces, the nucleus might be expected to become unstable and then break up into other nuclei. Actuated by these general ideas, I made in 1919 some experiments to test whether any evidence of transformation could be obtained when α-particles were used to bombard matter. The experiments were of a simple type; a preparation of radium served as a source of α-rays and the scintillation method was used to detect the presence of any new types of particles. It is well known that each α-particle falling on a preparation of zinc sulfide gives a flash of light, a scintillation, which is easily seen in a darkened room, and it was to be expected that any fast charged particle liberated from the bombarded matter would indicate its presence by a scintillation. When α-particles were used to bombard the gas oxygen, no new effect was observed. When, however, nitrogen gas was substituted, a number of scintillations were observed far beyond the distance of travel of the α-particles. Special experiments showed that these scintillations were produced by charged hydrogen atoms which we now call protons. The appearance of fast protons in these experiments could only be explained by supposing that they arose from the transformation of some of the nitrogen nuclei as a result of α-particle bombardment. This was the first time that definite evidence was obtained that an atom could be transformed by artificial methods. In the light of later experiments by Blackett, the general mechanism of this transformation became clear. It was found that the α-particle must actually penetrate into the nitrogen nucleus and be captured by it. As a consequence of this profound disturbance, a proton was ejected with high speed from the new nucleus. Let us for a moment consider the simple arithmetic of this process. The mass of the nitrogen nucleus is 14 and its nuclear charge 7 units. The capture of an α-particle of mass 4 and nuclear charge 2 raises the mass to 18 and the charge to 9, while the loss of a

proton of mass 1 and charge 1 results in the formation of an atom of mass 17 and charge 8. Now the oxygen nucleus has a charge 8, so that as a result of the interaction with an α-particle, the nitrogen nucleus is changed into a nucleus of oxygen. It will be noted that the mass of the oxygen nucleus formed in this way is 17 and not 16 as ordinarily observed. It was only later that the presence of an isotope of mass 17 in small quantity in ordinary oxygen was disclosed by direct experiments of another kind. In subsequent investigations with Dr. Chadwick, the methods of observation were much improved and it became clear that at least twelve light elements could be transformed by α-particle bombardment, and in every case protons were ejected, the number and speed varying from element to element. It seems probable that the process of transformation is similar in all cases to that found for nitrogen. The α-particle is captured and the new atom that is formed has a mass 3 units greater and a charge of 1 unit higher than the original atom. In other words, we have succeeded with each of these twelve elements in turning one of their atoms into the atom of the element next higher in the normal order of the elements.

It must be borne in mind that the amount of new matter formed in this way is exceedingly minute—far too small to examine by ordinary chemical methods. Success has only been obtained by the development of delicate methods of counting single atoms of matter. On account of the minute target area of a nucleus, the chance of a direct hit by an α-particle is very small. In the case of nitrogen, only about one α-particle in 100,000 is effective in causing a transformation, and for the element aluminium the chance is still smaller—about one in a million. Of course, the α-particles in these experiments are not aimed at the nuclei, but are emitted at random in all directions, and occasionally one of them by chance happens to approach closely enough to a nucleus to be captured.

While a number of light elements could be transformed by these methods, some, like lithium, carbon and oxygen, appeared to be unchanged by α-particle bombardment. The light element beryllium, however, showed a strange effect: no protons could be detected, but Bothe noticed the emission of a penetrating radiation which M. and Mme. Curie-Joliot found had unusual properties. Chadwick showed that this radiation consisted of a stream of fast particles of a new type which he named "neutrons." This new particle has about the same mass 1 as the proton, but has no electrical charge. The transformation of beryllium is thus of a different kind from that of most of the other light elements. As before, the α-particle is captured, but a high-speed neutron—not a proton—is expelled. By this process the nucleus of beryllium of mass 9 is changed into an atom of carbon accompanied by the ejection of a neutron.

This strange type of projectile has remarkable properties. On account of the absence of charge, the neutron is able to pass freely through atoms of matter with little if any loss of energy. It only makes its presence manifest when it collides with the nucleus of another atom. Feather has shown that fast neutrons are in turn effective in producing transformations of novel types in other elements. For example, he finds that both oxygen and nitrogen can be transformed with the emission of fast α-particles, while recently Harkins has shown that neutrons can also transform carbon and neon. The effect of the neutron on oxygen is of special interest, as the oxygen nucleus appears to be quite unaffected by bombardment either by α-particles or protons.

So far we have dealt with the transformations produced by fast particles which are themselves derived from the

spontaneous disintegration of radioactive elements. It soon became clear, however, that in order to extend our knowledge of this subject, far more abundant streams of fast projectiles of different kinds were essential. It was well known that the passage of an electric discharge through a gas at low pressure gives rise to a multitude of charged atoms and molecules of various kinds. If the charged atoms obtained in this way were accelerated in a vacuum by passing through a strong electric field, we might hope to obtain a copious stream of fast projectiles of different kinds for bombardment purposes. For example, when a discharge is passed through hydrogen it is easy to produce a stream of as many projectiles as are emitted by 100,000 grams of radium in the same time. By the use of high voltages, of the order of one million volts, it seemed likely that we could hope to obtain sufficiently fast particles to effect atomic transformations. In order to realize this purpose experimentally, elaborate electrical apparatus is required to generate the high voltage to be applied to the accelerating tube, and very fast pumps to keep the vacuum so low that no discharge can pass. After several years' hard work, Cockcroft and Walton in Cambridge succeeded in obtaining a strong beam of protons accelerated by half a million volts, suitable for bombarding purposes. When the accelerated protons were allowed to fall on a lithium target, a number of fast particles resembling α-particles were observed to emerge through a thin window opposite the target. These particles were counted by the scintillation method already referred to and also by automatic electrical methods which had been developed by Wynn Williams. It was soon shown that the particles from lithium were veritable α-particles, *i.e.*, helium nuclei of mass 4. These experiments of Cockcroft and Walton are of great interest and importance, for it is the first time that it has been shown possible to disrupt an atom by the use of fast particles produced by artificial methods in the laboratory. The general character of this transformation is now clear. Occasionally a proton of mass 1 enters the lithium nucleus of mass 7, and this then breaks up into two α-particles, each of mass 4. If this be true, the α-particles should fly off in nearly opposite directions. This has been verified and is beautifully shown in the photographs of the tracks of the α-particles obtained by Kirchner in Munich and by Dee and Walton in Cambridge.

We are not able to follow in detail the complicated and intense reactions which must occur in this transformation, for we are not yet certain of the constitution of the lithium nucleus before the capture of the bombarding proton. There seems to be no doubt that one at least of the helium nuclei ejected must have been formed *in situ* in the nucleus from the constituent neutrons and protons. In these types of nuclear reaction, more than one type of transformation may take place, and there is strong evidence that this is so in lithium, but the exact nature of these transformations is still unknown.

Cockcroft and Walton found that the number of α-particles observed increased rapidly with voltage, and was very large at 500,000 volts, while Oliphant has shown that the transformation of lithium can readily be detected for an accelerating voltage of only 30,000 volts. This result would have been difficult to understand on the old ideas, but is quite in accord with the new wave theory of matter. Gamow has shown that there is a chance, even if a very small one, for a comparatively slow particle to penetrate the strong electric barrier round the nucleus.

Cockcroft and Walton found that not only lithium, but also boron and fluorine, emitted α-particles under proton bombardment. The exact nature of

these transformations has not yet been settled, but it may be that the boron nucleus of mass 11 captures a proton and then breaks up into three α-particles, each of mass 4. In general it appears that proton bombardment leads to the emission of α-particles and the formation of elements of smaller mass, while α-particle bombardment causes a rise in mass of the resulting element.

I must now say a few words about some very important experiments with a new type of projectile which have been carried out by Professor Lawrence in the University of California. The work of a number of scientific men in the United States in the last two years has shown that ordinary hydrogen of mass 1 contains in very small quantity another isotope of mass 2. Although the quantity of this heavy hydrogen is only about one part in 6,000 of the main isotope, yet Professor Lewis, of the University of California, has succeeded by electrolytic methods in obtaining quantities of this heavy hydrogen in nearly a pure state. When we consider what a large part hydrogen plays in the structure of organic molecules, I need not emphasize the extraordinary interest of this discovery, both to chemistry and physics. This heavy hydrogen has the same chemical properties as ordinary hydrogen, but the water formed from it has a density 10 to 11 per cent. higher than ordinary water, and has also a different boiling and freezing point. Just before these experiments of Professor Lewis were undertaken, his colleague, Professor Lawrence, had devised a very ingenious method, depending on multiple acceleration, of obtaining protons of energy as high as 2 million volts. When this heavy hydrogen was used, the projectiles of mass 2 were found even more effective than protons in causing disintegration in many elements. For example, lithium was transformed into two α-particles each of speed greater than any α-particle observed from radioactive substances. In this case, the isotope of mass 6 appears to be involved. The capture of the hydrogen nucleus of mass 2 leads to the break-up of the nucleus into two α-particles flying off in opposite directions. This has been amply verified by the beautiful photographs obtained by Dee and Walton. In addition, many other atoms were found to be transformed by the same agency with the emission of α-particles, and in some cases very fast protons were also observed. The interpretation of this effect, which is shown even by some heavy elements, will surely prove of great importance in further developments. Professor Lewis kindly sent me some of this heavy water, and Dr. Oliphant and I have been able to confirm and extend these results with lithium, using only 100,000 volts on the discharge tube. There can be no doubt that this new kind of projectile will prove of great service in our attack on the transformation of the elements. It will be of great interest to compare in detail the types of transformation that arise from the use of these two kinds of hydrogen as projectiles.

It is interesting to consider the energy changes involved in these transformations. We have seen that a proton of energy corresponding to 30,000 volts can effect the transformation of lithium into two fast α-particles, which together have an energy equivalent of more than 16 million volts. Considering the individual process, the output of energy in the transmutation is more than 500 times greater than the energy carried by the proton. There is thus a great gain of energy in the single transmutation, but we must not forget that on an average more than 1,000 million protons of equal energy must be fired into the lithium before one happens to hit and enter the lithium nucleus. It is clear in this case that on the whole the energy derived from transmutation of the atom is small compared with the energy of the bom-

barding particles. There thus seems to be little prospect that we can hope to obtain a new source of power by these processes. It has sometimes been suggested, from analogy with ordinary explosives, that the transmutation of one atom might cause the transmutation of a neighboring nucleus, so that the explosion would spread throughout all the material. If this were true, we should long ago have had a gigantic explosion in our laboratories with no one remaining to tell the tale. The absence of these accidents indicates, as we should expect, that the explosion is confined to the individual nucleus and does not spread to the neighboring nuclei, which may be regarded as relatively far removed from the center of the explosion.

The general law of conservation of energy appears to hold in these intense nuclear explosions. On modern views there is a close connection between the mass of a body and the energy stored up in it. Any decrease of mass of a system is accompanied by the emission of a definite quantity of energy in one of its characteristic forms—for example, in the form of energy of motion of one or more of the particles concerned, or in the emission of radiation in the form of x-rays, or possibly both types of energy together. Now, in the lithium transformation, the relative masses of the proton, nucleus and α-particle are known with considerable accuracy. When we take into account the change of mass of the system before and after the nuclear explosion, and the kinetic energy of the expelled α-particles, we find that there is a close balance showing that this generalized form of conservation of energy holds within the accuracy of the observations. It is to be hoped that this law of conservation will prove a reliable guide in interpreting other types of nuclear reactions.

My listeners may quite naturally ask why these experiments on transmutation should excite such interest in the scientific world. It is not that the experimenter is searching for a new source of power or the production of rare and costly elements by new methods. The real reason lies deeper, and is bound up with the urge and fascination of a search into one of the deepest secrets of nature. Until a few years ago, we had to be content with the knowledge that the whole of matter in the universe, including our own bodies, was made up of ninety or more distinct chemical elements, but we had little definite knowledge of the inner structure of their atoms or of the processes by which one element could be converted into another. Now, for the first time, we are able to investigate these problems by direct experiments in the laboratory, and we are hopeful we shall soon add widely to our knowledge. The information so gained can not but widen our outlook on the nature of matter, but must also have a direct bearing on many problems of cosmical physics. For example, in the furnace of the sun and other hot stars, the electrons, protons, neutrons and atoms present must be endowed with high average velocities owing to thermal agitation. It is thus to be expected that the processes both of disintegration and aggregation of nuclei, such as are observed in the laboratory, should be operative on a vast scale for all nuclei, and that a kind of equilibrium should be set up between those two opposing agencies of dissociation and association for each type of atomic nucleus. It is well known that the abundance of the elements in our earth's crust varies very widely. Some elements like iron, nickel and oxygen are abundant, whilst others like lithium, platinum and gold are relatively rare. The information to be gained in our laboratories on the efficiency of various types of agencies in transforming atoms may help us to throw light on the reason for the

relative abundance of different elements in our earth, and thus in the sun from which our earth is believed to be derived.

In conclusion, let me say a word on the prospects of obtaining further knowledge of transmutation in the near future. While it is dangerous to prophesy in science, the main lines of attack are sufficiently clear to look at any rate a short distance ahead. In the first place, plans are being matured in many laboratories throughout the world to obtain much higher voltages and faster particles of all kinds for a further intensive attack on this problem. Van de Graaff has devised a new type of electrostatic generator whereby he hopes soon to obtain a steady potential of ten million volts with which to accelerate atoms in a discharge tube. The magnitude of this voltage may be gauged from the fact that it will give a miniature lightning flash more than fifty feet long. Lawrence, by a special method of multiple acceleration, hopes to obtain projectiles with energies greater even than those carried by the α-particles from radium. Observations are also being made on the transformation effects of the extremely energetic particles present in the cosmic rays which pass through our atmosphere. Many of these have an energy of one hundred million volts, while some are believed to have an energy of more than one thousand million volts. No doubt also the possibilities of transmutation by high frequency radiation of the x-ray type will be carefully examined. There seems to be little doubt that by the use of still faster particles of different kinds and possibly by other agencies, we may hope in the next few years to observe the transmutation of some of the heavier elements on a small scale. As we have seen, a successful method of attack on the general problem has now been opened up, and extraordinarily powerful yet delicate devices are available for studying the diverse effects which may arise during the transformations.

As one whose scientific life has been largely devoted to investigations on the structure and transformation of the atom, I watch with much interest and enthusiasm the development of these beautiful experiments to add to our knowledge of the constitution of nuclei. No one can be certain what strange particles or unexpected phenomena may not appear. I know of no more enthralling adventure of the human mind than this voyage of discovery into the almost unexplored world of the atomic nucleus.

APES, MEN AND TEETH

By Dr. EARNEST A. HOOTON
PROFESSOR OF ANTHROPOLOGY, HARVARD UNIVERSITY

TEETH tell the tale of human evolution better than any other bodily structure. No, I have not forgotten brains. But we do not understand the evolution of the human brain. Our brains are apparently much too big for the use we make of them. Certainly, neither we nor our immediate or remote ancestors have taken thought sufficiently to add many cubic centimeters to our cranial capacities. Yet here we are—all decked out in our 7¼ hats—and no place to go. We have less reason to be proud of our brains than to be ashamed of our teeth.

Teeth seem to be a distasteful subject for popular consideration. They are unpleasantly reminiscent of the apprehensive minutes spent in the dental waiting room with the futile distraction of back numbers of cheery periodicals—and other far worse experiences. Yet our teeth have had an illustrious past; they have a serviceable present, and with due conservation they will continue to perform an indispensable function in the future of man. But if the human dentition breaks down, it will carry with it in its fall the human species.

You must know the history of the teeth in order to appreciate them, and because this history epitomizes human evolution. The control of future human evolution is now in man's own hands—or perhaps rather in his teeth.

SHORT HISTORY OF TEETH

Teeth are the most nearly imperishable relics of the vertebrate body. If an animal's teeth last until death, they will continue to defy the destructive action of time and the elements—sometimes for millions of years. After death the soft parts of the animal body decay rapidly. The bones are much tougher. But bones are frequently crushed into dust or dissolved by the action of chemicals in the earth. Furthermore, they are often and perhaps usually devoured by carnivorous animals for which they are a *bonne bouche*. But teeth are singularly unpalatable and indigestible morsels. No animal eats them or, if it does, manages to digest them. They remain as monuments of extinct species. This is peculiarly fortunate for the student of evolution, since the teeth are not only the most durable, but also the most instructive of bodily parts.

Teeth are derived from scales—as are also nails and hair. In the shark—one of the most primitive of existing vertebrates—the skeleton is still cartilaginous rather than bony, and the teeth are rows of modified and sharp-pointed scales which succeed each other in series, a fresh row rising up to take the place of its worn-out predecessor. But in some sharks the teeth form a sort of continuous and blunt pavement. The kind of teeth which grow up in successive rows are laterally compressed cones with cutting edges, at the base of which two or more smaller cones may be developed. But in one existing and several extinct groups the hinder teeth have already developed blunt crowns for crushing the food. Sharks are next to the oldest fishes known, and first appear in the Devonian period—far back in the Primary era (350 million years ago, according to most recent radioactive scales of time).

It is hardly necessary to state that teeth are primarily for the purpose of grasping food and biting it off, and secondarily for the purpose of chopping or crushing it up into pieces small enough to be swallowed and digested.

The mouth of an animal naturally is situated at the head end, in which the sense organs and nervous system are concentrated. This end goes first and the intake of food is conveniently at the prow or snout and the outgo of waste products at the stern or tail. A primitive vertebrate needs some sort of snout or projection of the facial skeleton to carry the smelling and biting apparatus well in advance of the visual organs. It is desirable to get one's teeth and even one's nose into his food, if one is a grazing animal—but never the eyes. So the snout is an ancient vertebrate inheritance—rendered obsolete only by hand-feeding in the Primates and man. A long snout generally goes with a shortage of brains, over-emphasis of the sense of smell in brain area and a generally inferior zoological position.

In the Devonian period, 350 millions of years ago or more, there also appear progressive bony fishes with teeth sharply differentiated in form from scales, covering the margins and inner sides of the jaws and the roof of the mouth. The marginal teeth are pointed with complexly infolded bases. These teeth are now often set in sockets.

The most primitive teeth, such as the shark possesses, are of a predatory grasping type. In later and more evolved fishes the jaws become adapted for various purposes—nibbling, grinding, sucking, and the like.

The first land-living, air-breathing vertebrates seem to have developed from the lungfishes of the Middle Devonian. This group of lungfishes is represented to-day by a few degenerate survivors in Africa, Australia and South America, some of which come up to the surface to take an occasional gulp of air, while others breathe exclusively through the lungs during the dry season, being immured in a sort of cocoon in the mud. Thus the first breathing may have been done in a mud hut. The teeth are the same as before—with elaborately infolded bases.

Apparently as far back as the middle of the Devonian period some of these lungfishes got to living permanently on land, breathing continuously by means of lungs instead of gills, and crawling around some way or other by using their paired pectoral and pelvic fins as paddles, props, and eventually as limbs. Just how the fins developed into limbs is still a mystery—but they did. The teeth changed very little. So the amphibians, the first four-footed, air-breathing vertebrates, came into being. They still had strong predatory jaws with sharp pointed teeth—capable, however, of deploying into various specializations of types for crushing shelled invertebrates, herbivorous diet, fish-catching, et cetera.

The first reptiles developed from amphibians in the Carboniferous period, principally by getting rid of the tadpole stage, characteristic of the latter. For the eggs of amphibians are laid in the water, and the young at first breathe through gills and only in adult stages become air-breathing and land-dwelling. Reptiles, on the contrary, lay their eggs on land, and the young are lung-breathers from birth. Reptiles must have come upon the stage some 200 millions of years ago.

In some of the early but progressive forms the teeth have begun to lose their infolded bases and have tended to become simple peg-like cones, embedded in sockets, and all alike—fore and aft. The primitive reptile forms seem to have been more or less predatory and carnivorous. The process of differentiation of teeth into different forms according to their location in the jaws had already begun. Obviously, the teeth at the front end of the jaws should be shaped for cutting and piercing, because that is the end of the jaws with which bites must be taken. These anterior teeth sweep through a greater arc and with a greater velocity than the back teeth. At the corners of the jaw the primitive reptilian peg-like form tends to be preserved in

the canines or tusks—used for piercing and holding, and the front teeth may be modified into chisel forms for cutting—the incisors. The farther back in the jaw the teeth are, the greater the leverage of the jaws and the more force may be brought to bear upon the teeth. These, however, move through a smaller arc than the front teeth. Consequently, they are better adapted for crushing and grinding. If you have lost your back teeth, you realize that chewing with the front teeth is both public and ineffective.

Some of these early reptiles began to be suspiciously like mammals. Instead of going on their bellies, or waddling with their knees and elbows bent and thrust out sideways from the body, they managed to get their fore and hind legs well under their bodies, straightened them a bit, perhaps, and really were progressive. They "got going." They had two sets of teeth—not simultaneously, but successively—even as you and I. One of these was a milk set to carry on with while their jaws were growing, the other a "permanent" set which was supposed to last them the rest of their lives—and probably did, contrary to our common experience. The mammal-like reptiles did not content themselves with monotonous rows of peg teeth, but boasted incisors, canines, premolars and molars—in fact, all the recognized and respectable varieties. If you do not believe this, go to South Africa and dig up a Therapsid from the Triassic beds. No doubt any one there can direct you.

From these advanced and progressive mammal-like reptiles—not slimly, crawling marsh denizens, but dry land-dwellers—the mammals evolved in the Triassic period. Throughout the Age of Reptiles (say from 200,000,000 B. C. to 60,000,000 B. C.—a few millions more or less, if you like) mammals apparently remained wretched and insignificant little creatures, of small importance in the zoological world. They were lying low. Probably the earliest of them were insectivorous (insect-eating). They seem to have had four incisors, one canine, five premolars and six molars, on each side above and below. Probably the molar teeth had already begun to take on a three-cusped triangular form—suitable for crushing bugs.

At any rate, in some fashion or other, the molar teeth became broadened for grinding and developed in the upper jaw three cones or cusps and in the lower three cusps and a crushing basin, so that the upper and lower teeth efficiently interlocked for chewing purposes.[1]

Because they were puny and crafty—or modest and self-effacing—these small insectivorous mammals skulked in the underbrush and slunk out of the way of the giant reptiles of the Secondary Era, biding their time until they should develop into the masters of the world. This period of incipient and suppressed mammals seems to have lasted for about 140 million years—until 60 millions of years ago, according to radioactive time scales. During this long interval the tiny mammals developed in various directions in bodily form and tooth adaptations, but the stock which gave rise to the Primates (lemurs, tarsiers, monkeys, apes and man) was arboreal. It is represented to-day by the primitive tree-shrews.

Here I must descant upon the advantages of arboreal life for a small mammal. The forest nursery offers a comparatively safe existence. Large predatory carnivores find it unprofitable to chase the small animal up trees. The

[1] This may seem unimportant to you, but just stop to consider. If you are unable to chew your food properly, you must either subsist on soft fodder and "slops" or swallow large gobbets, thereby putting a huge task upon your digestive apparatus. Simultaneous digestion and cerebration are incompatible. If you spend all your time digesting, you will never learn to think.

agile climber is secure, providing he does not fall out of the tree. He can eat leaves, shoots, nuts, fruits, birds' eggs and insects and birds, if he can catch them. Nests may be built and the young comfortably reared. But more than this, arboreal life puts a premium on sight. Smell is the most important sense for a small ground animal, both for finding food and for avoiding enemies. The snout is both an olfactory and a tactile organ. The little animal "noses its way" through life. But supposing he climbs a tree! Smelling becomes relatively unimportant, acuity of hearing is not as essential as on the ground. But the arboreal animal must "keep its eyes peeled"!

The insect-eating pre-Primates had long snouts with moist muzzles, eyes laterally directed, five digits on the hands and feet, two incisors, one canine, four premolars and three molars on each side, above and below. They were small quadruped climbers, long of tails and short of brains, with dietetic habits which extended to fruits, leaves, shoots and nuts as well as insects.

From these humble little brutes sprung the Primates, at the beginning of the Tertiary Epoch, 60 millions of years ago. At first there was nothing higher than lemurs—small arboreal catlike animals whose descendants may still be seen in the forest of Madagascar, Africa and the Indo-Malayan region (or in the better zoological gardens). The lemur, however, represents a considerable advance over the insectivore. Primates are characteristically equipped with five digits on hands and feet which are provided with flat nails instead of claws and the thumbs and great toes of which may be opposed to the outer digits in grasping boughs. This opposability of thumbs and great toes is the secret of the manual dexterity of Primates and culminates in the mechanical supremacy of man, although man's foot has ceased to be a grasping organ.

Lemurs are omnivorous. Pause and contemplate the advantages of being able to eat almost anything. (If you live in a boarding-house, you know this already.) In the struggle for existence, it often means survival. Even in human society a good digestion and an ability to eat all kinds of food is better than riches or even intelligence. The modern lemurs have lower incisor teeth which lean forward and are supposed to be used for combing their fur; they have three premolars and three molars. Apparently, when the teeth become differentiated and the diet is generalized, fewer teeth avail the animal. The earliest lemuroids are found in the Eocene in North America—the first of the Tertiary geological deposits. Now we have to look for them in out-of-the-way tropical forests in the Old World.

The tarsioids are little pop-eyed cousins of the lemurs—geologically about as old and in structure almost as primitive. But they were more progressive and upstanding, or rather upsitting. In the first place, they hopped from bough to bough, instead of running on all fours along the branches. That gave them a free pair of hands to explore, to scratch, and wherewith to feed themselves and to pluck of fruits of the tree of knowledge. (The tarsiers were, of course, arboreal. The modern descendants are found in the forests of the Indo-Malayan archipelago.) The number and kinds of their teeth are the same as in the lemurs, but the snout is shortened, the brain case is relatively large and the orbits of the eye are directed forward, making the fields of sight overlap so that stereoscopic vision results. These tarsiers went right on eating everything they could find in the trees and remained unspecialized in teeth, but began to specialize in eyesight, in tactile sense, perhaps even in common sense. At any rate, the habit of hand-feeding, the shorter snout, the better vision and the larger brain are all inextricably evolved in the organ-

ism of the little omnivorous animal. The tarsier is the infant prodigy of the Primates.

Out of some primitive but progressive tarsioid of the Eocene period (some 55 millions of years ago) there evolved the stocks which have led to the higher Primates (monkeys, apes and man). We may profitably pause to consider very briefly a tiny fossil monkey, named Parapithecus, found in the Lower Oligocene of Egypt (dated about 35 million years ago). This little animal, represented only by a lower jaw and teeth, stands, in the opinion of Professor W. K. Gregory, at or very near the line of descent leading to the anthropoid apes and eventually to man. It may be regarded as a generalized super-tarsioid, or pre-monkey of the Old World. It already has the human dental formula: two incisors, one canine, two premolars and three molars, on each side and in both jaws. It has small and unspecialized canine teeth and blunt premolars and molars which would seem to preclude carnivorous or flesh-eating habits. Its incisors, leaning gently forward, and its low-cusped cheek teeth seem to point to a mixed diet—perhaps insects, fruits, birds' eggs and small reptiles. In fact, it ate hors d'oeuvres, omelette, entrée and dessert. From such an early form the Old World monkeys diverged, specializing in different directions, but in general tending to display an elongation of the canines, useful in fighting and in piercing the rinds of tough fruits, and a pairing of the molar cusps, four in each tooth, in groups of two. These molar cusps have now become quadrate, having lost the earlier triangular form.[2]

We need only two more steps in dental evolution to bring us up to man, but we have to "step high." The first of these is taken in the most ancient and primitive fossil anthropoid ape—Propliopithecus—again a find of the Lower Oligocene of Egypt. This early anthropoid with the jaw-breaking name may have lived some 35 millions of years ago. Nothing survives of this little ape except a lower jaw with its teeth, but its lower canines were smaller than those of recent gibbons, its snout shorter and its molar teeth less specialized in form. Propliopithecus was no bigger than a human suckling; he was a proto-ape with a small brain and no chin; but that little jaw and those generalized teeth mark out the pattern of development which eventually lead to man. Propliopithecus—not Tut-ankh-Amen—is Egypt's crowning glory.

The final step preceding the arrival at the human plane of dental and general body development may be studied in the remains of the great Dryopithecus family of generalized giant apes, from which it seems most likely that the gorilla, the chimpanzee and man eventually developed as separate modern descendants. Remains of the Dryopithecus family are found in North Africa, in Europe and in the Siwalik Hills of India, at the foot of the Himalayas. This family was flourishing in mid-Miocene times—roughly 14 million years ago. The stems leading to the modern apes of Asia—the gibbon and the orang-utan—had previously diverged from the common anthropoid-human trunk. Jaws of members of the Dryopithecus family clearly show the ancestral pattern of the molar teeth which is found in the chimpanzee, the gorilla and man. These apes had the same number and kinds of teeth as you have, but the lower canines were large and pointed with erect tips. The hinder premolars were bicuspid as yours are. The lower molars were arranged with five main cusps, three on the outside, two on the inside, and sometimes a smaller hinder cusp in the middle. This is Professor Gregory's "Dryopithecus pattern," which is preserved in the molar teeth of most fossil men, of many recent savages and in your first

[2] But four-course dinners do not necessarily demand four-cusped teeth.

and second lower molars and in mine—if we still have them and are not too degenerate.

We must conceive these generalized precursors of man and the African great apes as large Primates with projecting jaws and only moderately large brains, who progressed through the trees by brachiating—swinging by the arms; who had prehensile feet as well as grasping hands. They were probably not specialized in the tremendous elongation of the arms that we observe in the gorilla, the chimpanzee and the orangutan of to-day—animals which have displayed the conservatism which limits evolutionary development and which has induced them to remain tree-dwellers, or half-hearted quadrupedal ground-dwellers like the gorilla, long after their size, strength, intelligence and dietary requirements demanded a fuller and richer existence as erect, terrestrial bipeds. Note that man, like Zaccheus, owes his importance to the fact that, having climbed a tree, he straightway came down.

One of these Dryopithecus lines had the supreme gift of super-anthropoid intelligence and initiative. Its members took to the ground and eventually stood up on their hind legs, having developed stable supporting feet from the ancient Primate grasping organs. Their arms and hands were set free for prehension. They began to use weapons and tools—a step which initiated human culture and took the strain off their jaws and teeth, previously employed for offensive and defensive as well as masticatory purposes. Gradually the snout shrank back, and this recession seems to have been accompanied by an overgrowth of the brain. These are associated evolutionary phenomena, but the one did not necessarily cause the other.

Some pessimistic paleontologists (by which I mean the ponderous pundits who study the remains of extinct animals) think that the line of anthropoids which came down from the trees and developed into man either fell out of the branches or was pushed out by a deforestation of the area which it inhabited. This is a very controversial subject, and I must place myself definitely "on the side of the angels." I do not give man full credit for his evolution from lower forms, but I am convinced that it was the ability to grasp an opportunity and the gift of initiative supreme in this humanoid stock which urged it forward on the path of humanity. If this be orthogenesis, Lamarckianism or any other sort of biological treason—make the most of it!

Now I am by no means contesting that man developed from a shark purely through shifting the form and function of his teeth—or that he ate himself up to a human status. Nothing that a Primate does or does not do with his teeth makes him a man or a gorilla. But I can determine whether you are a man or a gorilla as quickly and correctly by looking at your teeth as by observing any other feature of your anatomy or any item of your behavior. In other words, teeth tell the story of human relationship, but they do not explain why we have this possibly disreputable ancestry. It is there, whether we admit it or not. However distasteful and disconcerting these ancestral skeletons may be, they are there in the family closet![3]

The Teeth of Fossil Man

But we must pursue the rise and decline of the human dentition through fossil man and down to modern and degenerate times. The earliest representative of the humanoid stock of which we possess remains is the *Pithecanthropus erectus* of Java—still nearly halfway down to the ape in brain size, but with a thigh bone which indicates

[3] Throughout this section I have levied a very heavy toll upon Professor W. K. Gregory's work, "The Origin and Evolution of the Human Dentition," *The Journal of Dental Research*, 1920, 1931.

that he strode erect through the forests, even as you and I over the pavements. He belongs back in the beginning of the Pleistocene—nearly one million years ago. What kind of teeth had Pithecanthropus? We have only a couple of molars to go by. They are large and with strongly divergent roots and fangs, but they already show some degeneration and cusp reduction which is essentially human and not anthropoid, although one of them recalls to Professor Gregory the fine old Dryopithecus pattern.

Somewhat more advanced in brain development than Pithecanthropus are the recently discovered men of the Sinanthropus type, found in deposits of the Lower Pleistocene near Peking, and dating back probably to the early quarter of that period—750,000 years ago. These early Pekinese had jaws with incipient chins—a jump ahead of the chimpanzee, bath-tub shaped jaw. The canines were not projecting as in anthropoid apes. The molar teeth were low-crowned like those of a chimpanzee —the molar cusps in the lower jaw being five in number like the ancient Dryopithecus pattern. Curiously, the front halves of the molar teeth are ultra-human or almost degenerate, and the back halves are ape-like. But the queerest feature of these ancient Chinese teeth is found in the pulp cavities of the molars. The crown of a tooth is the part above the gum; the roots are sunken into the alveolar bony sockets of the jaw. Through the roots run fine canals into a central cavity which is filled with pulp—blood-vessels and nerves. The walls of the pulp cavities are of dentine or cement, and the outer layer of the crown of the tooth is hard enamel. In modern man and the apes the pulp cavities of the molar teeth are small and do not extend down below the crowns. But in Sinanthropus, and in the later Heidelberg and Neanderthaloid races, the pulp cavities are enlarged and the body of the tooth with the pulp cavity is prolonged downward below the alveolar borders of the jaw at the expense of the roots, which are short.

This specialization is called taurodontism, because it occurs in animals which chew the cud. It is exactly the opposite of the cynodont or dog-tooth condition found in the anthropoid apes and in modern man. Must we infer that the ancient precursor in China was a ruminant? I think not. He was probably omnivorous and knew neither rice nor birds' nest soup. But the importance of this specialization is that it seems to remove Sinanthropus, and the other ancient types which show it, from the direct line of descent which leads to modern man. The premature herbivore-like specialization of molar teeth is peculiar to Sinanthropus and the low-browed Heidelbergers and Neanderthaloids.

I do not propose in this article to pick over the teeth of every fossil type of man, but merely to jab at a few suspicious and tender spots—marking significant findings—as your dentist when he is looking for cavities. In general, the successively higher types of fossil man show a decrease and recession of the jaws, a gradual thrusting forth of the chin, and the change of the palate shape from a long, narrow U type found in the apes and associated with snoutiness to a parabolic type in which the dental arches spread from front to back, no doubt in correlation with the increasing breadth of the brain case to which the jaws are hafted. The teeth themselves gradually become smaller, the molars wider and shorter, and the number of cusps tends toward reduction in both upper and lower jaws. The molar teeth also get smaller going from the first back to the third or wisdom tooth, whereas in some fossil types and anthropoid apes they increase in size from front to rear.

Probably the most striking change from the anthropoid ape type to human

type has to do with the reduction of the great projecting tusk-like canines, which in apes interlock, stop skidding of the jaws, and effectually prevent the lateral and rotary movements of the jaws which are characteristic of primitive man, but seem to be retained in effete civilization principally among gum-chewing stenographers and tobacco-quid-masticating rustics. It is here that we run upon an unsuspected snag in navigating the little known stream of human dental evolution. For the Piltdown skull, familiarly known as Eoanthropus or the Dawn Lady, unexpectedly turned up in a Lower Pleistocene deposit with a beautifully formed brain case, complete with high brow and capacious brain, but with a chinless jaw like that of a chimpanzee and a projecting tusk of a canine which belongs in that jaw. The molar teeth of this anomalous and contrary female were low, narrow and long—highly reminiscent of the chimpanzee—and possessing in the mandible the ancestral five-cusped Dryopithecus pattern. But in some important respects they approximate a human type.

Confronted by this highly contradictory combination of ape-like jaw and teeth and wholly human brain case, some anatomical skeptics have attempted to cut the Gordian knot by attributing the advanced brain case to some pre-English Boadicea and the jaw to her pet chimpanzee. However, this view fails to account for the lady's missing mandible and the ape's lost brain case, and is based upon a mistaken idea that the course of human evolution was symmetrical in all parts—that all types advanced harmoniously from the ape to the human form. We know now that human evolution was a multiple and asymmetrical process, involving many different types struggling upward toward humanity, some precocious in one part of the anatomy and laggard in another part, while others displayed reverse combinations in the association of prematurely human and retardedly anthropoidal parts. Thus Pithecanthropus got his human gait and legs before he attained a human size of brain, and Sinanthropus was scarcely human in brain size but prematurely specialized on the human side in certain features of dentition. So we must accept the Piltdown lady as a mysterious compromise who may be in our own ancestral line in spite of her chinless chimpanzee-like jaw and projecting canines. The pulp cavities of her molar teeth, like ours and those of our anthropoid cousins, were not enlarged. Her canines were beginning to shift from the sides of the jaws to the front and she may have been able to chew from the outside in toward the middle, as all good primitive men and women chew. This is a sort of motion which can not be managed by the apes on account of their interlocking canines.

It is sad to relate that fossil men of glacial times already show clear hints of certain dental degeneration. The Ehringsdorf jaw, which may be 500,000 years old or perhaps only 250,000 years, shows definite decrease in size and degeneration of the cusps of the third molar or wisdom tooth. Some of the Neanderthalers have upper third molars with only three cusps instead of the primitive four.

However, the most shocking person in the array of fossil ancestors is the Rhodesian man, dug up in a zinc mine of South Central Africa and equipped with the most gorilla-like beetling bony brow-ridges, the longest face, the largest palate and the worst teeth of antiquity. Not only has this fellow reduced and degenerate wisdom teeth, but nearly all his teeth have been attacked by caries or decay; there were abscesses at the roots of many, and the "danger-line" was riddled with pyorrhea—a septic condition of the gums which leads to eating away of the bony tooth sockets, loosening of the teeth, the entrance of all sorts

of poisons into the system through the absorption of pus, to say nothing of "pink toothbrush." This Rhodesian man had an abscessed condition of the mastoid region, which had drained right out through the bone. In fact, he sorely needed a dentist.

The Decline of Human Dentition

Savage or primitive types of modern forms of man have smaller teeth than the fossil men, but their palates are broad and capacious, their incisor teeth meet edge-to-edge in most cases; their molars have four good cusps in the upper jaw and five in the lower, and the third molars are usually not much reduced and not greatly retarded in eruption. The good old Dryopithecus pattern of molar teeth evinces their illustrious ancestry.

Civilized man has smaller teeth and frequently a small contracted palate. Usually the lower incisor teeth bite behind the upper incisors so that the latter overhang, giving rise to an "overbite" and often, when they protrude, a "buck-toothed" effect. But, worse than this, the lower and upper teeth frequently fail to erupt in their proper positions, so that they do not engage efficiently and permit proper mastication of food. This malformation of the jaws is called "malocclusion" and comes in a variety of forms. Its cause is complicated and obscure, but seems to lie in hereditary evolutionary tendencies of a degenerative nature, possibly induced to some extent by lack of proper healthy exercising of the jaws and teeth—a consequence of the excessive use of soft cooked foods.

Malocclusion is principally a phenomenon of modern civilization and it is increasing most alarmingly. It must be combatted. The dental specialists who are striving against this retrogressive tendency in human evolution are called orthodontists. Theirs is the difficult task of finding out the cause of this malformation and eradicating its disastrous effects. They are most skilled to warp and move and straighten teeth so as to bring them back into efficiency and symmetry, but as yet they do not know how to keep them there, just where the teeth should be moved and why they erupt out of position in the first instance.

The other two great manifestations of the decline in the human dentition are caries or decay and pyorrhea. Most savages show few or no cavities in their teeth. They may wear their teeth down by eating gritty food, until the pulp cavities are exposed and the tooth dies and decays, but the primary caries—the eating away of the tooth by bacteriological or other destructive agencies in the mouth—is extremely rare—at least until the savage comes into contact with civilization, missionaries, canned foods, groceries and candy. But nine out of ten school children in the United States have decayed teeth, and civilized adults probably show nearly 100 per cent. of mouths which contain one or more carious teeth. This decay of the teeth means the introduction into the system of poisons which cause rheumatism and a host of major ailments which may follow this primary infection. Yet no one to-day knows the cause of dental caries. It may be partially a matter of diet and particularly caused by diets lacking in one or more of the necessary vitamins. But it is by no means exclusively due to diet, since primitive peoples living under a wide range of dietetic conditions usually manifest few if any ravages of this terrible disease.

Pyorrhea is a septic condition of the gums, which is even more obscure in origin and far more difficult to treat than simple dental caries. The bacteriological agencies present are to some extent known, but the cause is not the lack of use of a toothbrush, nor is the remedy to be found in frequent scrubbings

with this or that allegedly antiseptic toothpaste. Of course brushing the teeth is like buttering the baby's heel; it can not do any harm and it may do some good. This is always providing that the toothpaste used is not abrasive nor of such a nature as to attack the enamel. Of course the teeth should be kept clean, just as the feet should be kept clean. And the mouth and teeth which guard the digestive tract are much more vulnerable to germinal incursions than is the skin.

The facts that we must face are, in brief, that human teeth and the human mouth have become, possibly under the influence of civilization, the foci of infections that undermine the entire bodily health of the species and that degenerative tendencies in evolution have manifested themselves in modern man to such an extent that our jaws are too small for the teeth which they are supposed to accommodate, and that, as a consequence, these teeth erupt so irregularly that their functional efficiency is often entirely or nearly destroyed.

How to Stop Dental Degeneration

In my opinion there is one and only one course of action which will check the increase of dental disease and degeneration which may ultimately cause the extinction of the human species. This is to elevate the dental profession to a plane upon which it can command the services of our best research minds to study the causes and seek for the cures of these dental evils. Such an improvement of the quality of the dental profession is an indispensable prerequisite for the attacking of these tremendous pathological and evolutionary problems. No effective measures of public education in care of the teeth can be taken until dental practitioners cease to be tinkers and learn to be scientists. In making such a statement I by no means wish to belittle the tremendous progress in the field of dentistry which has already been made.

As a matter of fact, if I were asked in what occupations the United States indubitably leads the world, I should reply without hesitation "Dentistry and plumbing." American dentists have reached a pitch of mechanical skill which is equal to that of American surgeons. But carpentry is not enough. Stopping teeth does not stop tooth decay. In the dental profession to-day are many brilliant scientific minds and many practitioners of consummate skill whose aims are humanitarian rather than pecuniary, but there are too few of such men and they have been insufficiently trained.

The dental profession has been for too long a time a neglected and disowned orphan child of medicine and surgery. While millions have been lavished upon medical schools and hospitals, and upon medical and surgical research, almost nothing has been allotted for these purposes to dentistry. Our schools of dentistry have been forced to struggle along without endowments; their teaching staffs have consisted almost entirely of devoted but unpaid men who give part of their time to teaching, but have to make their living in practise.

The prerequisites for admission to dental schools have not been sufficiently high. In the past many schools have admitted high-school graduates and students with only one or two years of college preparation. This low standard of admission implies a supply of inferiorily educated men and a commercialized technical course, rather than the broad background of general education essential to the rigorous training of a professional school of medicine. As a result there has been very little scientific research in the dental school and what has been carried on has been principally commercial in its aim. The faculties of dental schools recognize these shortcomings and are striving to raise their

standards and to transform dentistry from a trade to a profession, from a craft to a science. But they can not succeed in any large measure until the public and the philanthropic foundations, and especially the medical profession itself, recognize the essential parity of dentistry with other branches of medical science.

I am well acquainted with only one dental school—that connected with an old and famous New England university. Like every other dental school, it has been regarded as a yellow dog trailing at the heels of the medical school. It has been slighted in endowment, in gifts for research, and generally neglected and half starved. Yet this dental school includes in its faculty some of the most enlightened, altruistic and scientifically minded teachers and research workers with whom I have been privileged to come into contact. It was the first university dental school in the world; it was the first to lengthen its academic year to nine months; the first to require written examinations; the first to demand graduation from a high school as an entrance requirement; among the first to increase that requirement to two years of college.

This institution is now seeking an endowment which is absolutely necessary for its proper development. Let us not attempt to evade the issue. Either we must spend the necessary sums to give dental research and dental practise their proper status in the medical profession, or we must spend vastly larger amounts upon dental tinkers, whose unpleasant duty it is to lean over the dental chairs in which we sit, gaze upon the shocking vista of human degeneration which our open mouths present, and attempt the hopeless task of stopping decay and sepsis. I firmly believe that the health of humanity is at stake, and that, unless steps are taken to discover preventives of tooth infection and correctives of dental deformation, the course of human evolution will lead downward to extinction.

THE RÔLE OF BACTERIA IN THE CYCLE OF LIFE IN THE SEA[1]

By Dr. SELMAN A. WAKSMAN

PROFESSOR OF SOIL MICROBIOLOGY, RUTGERS UNIVERSITY

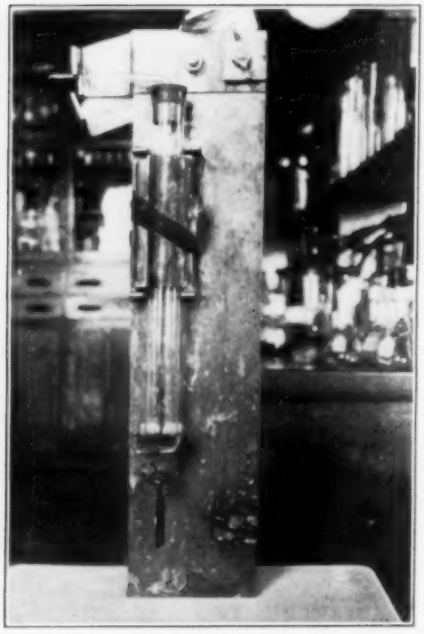
THE sea harbors an extensive population of bacteria, varying greatly in numbers and in the variety of their activities. This variation depends, in the case of the sea-water, on the distance from shore, depth of water, season of year, abundance of plankton and uniformity of mixing of the water, and in the case of the sea bottom, upon the nature of the bottom material, depth from the surface of the sediment, etc. These bacteria take part in a number of processes which are of considerable importance in the life of the plant and animal populations of the sea, namely, in the decomposition of plant and animal residues, in the transformation of their nitrogen to such an available form as ammonia and of their carbon to carbon dioxide, in the formation of nitrate as well as the reduction of nitrate, in the oxidation of sulfur and the reduction of sulfate, in the fixation of nitrogen, in the direct and indirect precipitation of calcium and iron, in the formation of organic matter or humus in the sea bottom and in the decomposition of this humus. To what extent these processes are absolutely essential in the growth of plant and animal life in the sea still remains to be determined.

The study of bacteria in the sea includes a series of problems in bacteriology and in biochemistry which are to be coordinated with other branches of oceanography, in order to establish the rôle of the bacteria in the marine processes. In most instances information on marine bacteriology has been gathered by individual investigators during short periods, using material obtained from few localities; less often the work is the result of an expedition, where limited facilities were offered for a detailed study of bacterial life and of bacterial processes under the natural conditions prevailing in the sea. Most of these investigations had a specific purpose of demonstrating either the presence or absence of certain bacteria in the sea, or of organisms capable of bringing about processes which are known to be of importance to marine life. Attempts to correlate the occurrence of a certain organism with an important marine process frequently led to generalizations which were later found to be totally unjustified.

If any phase of biology needs continuous study, it is that of bacteriology, because one deals here with living organisms, rather than with dead specimens, and one must study physiological processes rather than morphological structure. One can not bottle up some sea-water for 6 weeks or even days, then bring it to the laboratory and expect that the numbers and types of bacteria will have remained the same as under the natural conditions of the sea. One can not preserve bacteria, as one does animals or plants, then identify them, as an opportunity arises, since in most cases the bacteria are identified not by their appearance but by their activities.

The fact that a certain bacterium is active in a specific transformation in the laboratory is no proof as yet that it will be responsible for the same reaction in the sea. Samples of sea-water or of bot-

[1] Contribution No. 23 of the Woods Hole Oceanographic Institution and Journal Series paper of the New Jersey Agricultural Experiment Station, Department of Soil Microbiology.



SAMPLING TUBE

FOR COLLECTING, AT DIFFERENT DEPTHS, SAMPLES OF WATER UNDER STERILE CONDITIONS.

tom material removed from their environment and brought into the laboratory may give, within a very short period of time, frequently within a few hours, a bacterial population which is quite different quantitatively from the corresponding population in the sea itself; a number of factors may be responsible for this change.

In the case of the bacterial population of the sea, as in the case of soil bacteria or bacteria in inland waters and in sewage, one deals with mixed populations and not with pure cultures. It is not merely sufficient to isolate an organism, cultivate it and determine what it does in pure culture; it is far more important to determine what it does in its natural substrate and how these activities dovetail with the activities of other bacteria, as well as with the whole complex mass of higher plants and animals.

In order to illustrate the possible confusion that may arise from the investigation of a single bacterial process in the sea, it is sufficient to call attention to the study of the rôle of bacteria capable of reducing nitrate in certain important marine processes. The hypothesis of Drew concerning the precipitation of $CaCO_3$ in the tropics and that of Brandt concerning the insufficient plankton development in tropical seas, as compared with that of temperate and arctic regions, were based largely upon this one specific bacterial process. Not only was considerable importance attached to it, disregarding thereby numerous other chemical and bacteriological processes involved, but an attempt was even made to set up highly generalized theories concerning the whole system of metabolism in the sea on the basis of this process.

Drew has shown in 1913 that, in a sea-water medium containing nitrates and calcium salts of organic acids, precipitation of calcium carbonate takes place. This reaction was found to be a result of the reduction of nitrate by certain bacteria, which use the organic acid radicle as a source of energy. On the basis of this experiment, the theory

THE LABORATORY BOAT *ATLANTIS*

LEAVING FOR THE GULF OF MAINE FOR A SERIES OF CHEMICAL, BACTERIOLOGICAL AND PLANKTONOGRAPHIC INVESTIGATIONS.

CHART I. PLANT, ANIMAL AND BACTERIAL RELATIONSHIPS IN THE SEA

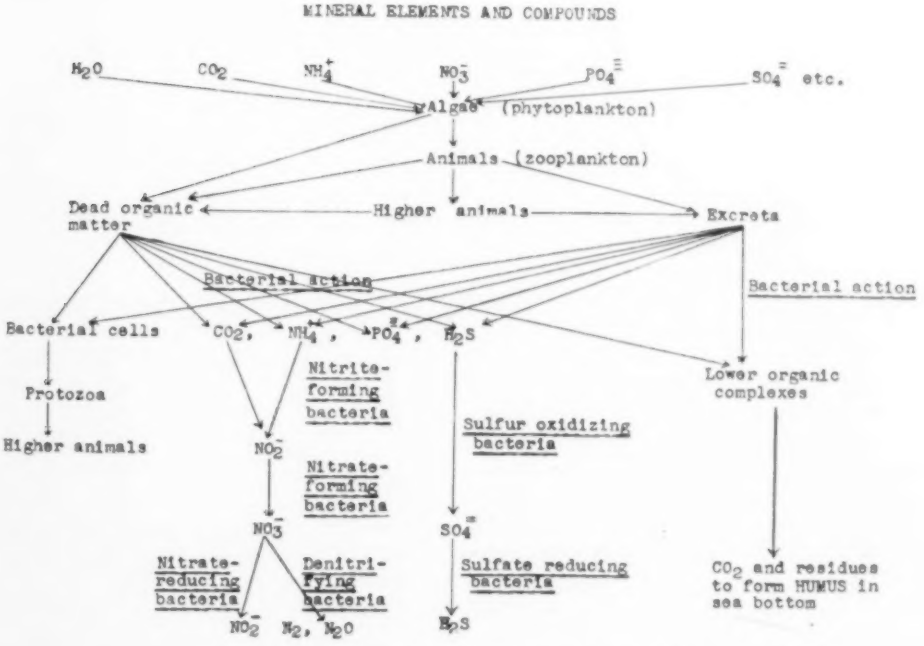
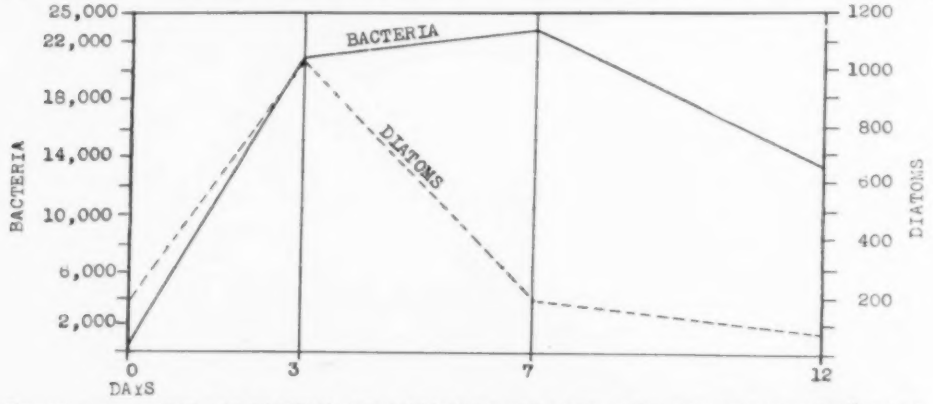


CHART II. RÔLE OF BACTERIA IN THE CYCLE OF LIFE IN THE SEA

was proposed that the precipitation of $CaCO_3$ in the chalk muds in the Bahama region, off the coast of Florida, and probably in other places is due to action of bacteria. Even granting that Drew was right in his conclusions, namely, that his experiments proved that precipitation of $CaCO_3$ in the sea may be due to the action of bacteria, he made two purely hypothetical assumptions not based upon any experimental evidence, which would tend to nullify these conclusions, as applied to large regions. These assumptions are that nitrates are produced in the sea in sufficiently large amounts and that sufficient quantities of organic acids are present in sea-water to bring about such an extensive process. However, the activities of the bacteria are not limited by their numbers but by the amount of available energy, the abundance of nutrients and favorable environmental conditions. Lipman concluded that calcium precipitation in large quantities in the sea can be more readily explained by purely physicochemical processes, although he did not deny the possibility that microorganisms may bring about, directly or indirectly, the precipitation of some calcium carbonate. Kellerman and Smith, who upheld Drew's hypothesis, believed that the denitrifying bacteria are specific "calcium bacteria," indicating thereby



CHANGES IN NUMBERS OF BACTERIA AND DIATOMS IN SEA-WATER CULTURES; NUMBERS IN 1 CC OF CULTURE.

bring about the dissolution of the calcium and to serve as an energy source to the nitrate-reducing bacteria. The mere fact that an organism can reduce nitrate in an artificial culture medium is no proof that this process forms an important phase of the activities of the organism under natural conditions. A great many pathogenic bacteria are able to reduce nitrate, although this substance does not occur in appreciable quantities in the blood or in other tissues where these bacteria are active.

In criticizing this hypothesis, C. B. Lipman suggested that the sea does not contain a sufficient number of bacteria that the process of calcium precipitation plays the predominant function in the life activities of these organisms. Molish went even a step further and described various new species of bacteria on the basis of their ability to cause the precipitation of calcium. These conceptions are hardly justified, since the reaction of calcium precipitation, even under Drew's experimental conditions, is only secondary in nature and does not form an important phase of the physiology of the bacteria. Further, in addition to various denitrifying bacteria, other organisms, such as urea and sulfate-reducing bacteria, are also able to bring

about the precipitation of calcium. Unfortunately, neither Drew nor those following him seemed to have been familiar with the fundamental work of Nadson on "Bacteria as Geological Agents" published nearly 30 years ago, which tended to illuminate this process.

The second hypothesis based upon the activities of nitrate-reducing bacteria was even more far-reaching in its application. Brandt was among the first to emphasize the important part played by bacteria in the cycle of life in the sea. He suggested the following explanation for the relative abundance of plankton in the arctic and temperate regions and its comparative poverty in the tropics. In warm regions, the denitrifying bacteria are very active and destroy the nitrates, thus bringing about a nitrogen minimum; in cold regions, where the denitrifying bacteria are not so active, the abundance of nitrate permits considerable plankton development. This hypothesis has had a considerable influence upon the subsequent development of research on the bacteria of the ocean. Assuming that the observations concerning the relative abundance of the plankton in the sea, under different climatic conditions, are correct, the explanation suggested is very much open to criticism, since one would have to establish first that nitrates are formed in the tropical regions as abundantly as in the temperate regions, that bacteria are more active in the tropics and that more energy, in the form of plant excreta or residues, is available in the tropical seas to enable those bacteria to reduce the nitrate. Possibly the more rapid disappearance of the organic residues in the tropical waters, due to the greater activity of the bacteria decomposing the organic matter, may have more to do with this phenomenon than the activities of the denitrifying bacteria. Recent studies by Butkewitsch established the fact that nitrate-reducing bacteria are

CONNECTING SAMPLING TUBE TO LINE

TUBE FOR SAMPLING OF MARINE MUD UNDER STERILE CONDITIONS

also found in cold regions as in the Barents Sea, while investigations carried out at the Woods Hole Oceanographic Institution brought out the fact that the activities of most of the nitrate-reducing bacteria in the sea are limited to the reduction of nitrate to nitrite and not to atmospheric nitrogen.

These two illustrations are sufficient to emphasize how certain limited observations on the activities of one group of bacteria isolated from the sea, namely,

PETERSEN GRAB
FOR SAMPLING OF MARINE BOTTOMS.

the denitrifying organisms, can be so magnified as to make them appear as among the most important members of the bacterial population of the sea. One should add here that Brandt's hypothesis was not accepted by Gran and other prominent oceanographers, who demonstrated that the available evidence is either insufficient or even contrary to it.

The Cycle of Life in the Sea and Bacterial Activities

A graphic representation of the rôle of bacteria in the cycle of life in the sea is given in Charts I and II. Chart I shows the general relation of the bacterial activities to the interrelationships of plants and animals in the sea and to the various degradation products, while a more detailed analysis of the specific marine processes in which bacteria are chiefly concerned is shown in Chart II.

According to Thienemann, the plankton consists of three groups of organisms: (1) "producers," comprising largely the chlorophyll-bearing diatoms and algae which build up organic substances from the inorganic nutrients dissolved in the water; (2) "consumers," or the animal representatives of the plankton which feed upon the living or dead members of the phytoplankton or their metabolic products; (3) "reducers," comprising the bacteria, which decompose and mineralize the high-molecular compounds formed by the producers and consumers. The last two groups are in definite nutritional relations to one another. One can easily enlarge upon this idea and include among the consumers also the higher animals, which feed both upon producers and consumers of a lower order; among the reducers one can include not only the bacteria of the plankton but also the bacteria of the sea bottom which take an active part in the destruction of plant and animal residues in the sea, as well as the animal population of the sea. Certain groups of bacteria will also be found among the producers, such as the nitrogen-fixing bacteria; bacteria may also be considered as consumers, since they synthesize bacterial cell substance. One can add a fourth group, namely, "transformers," which comprise those bacteria, like the nitrifying, sulfur-oxidizing, nitrate-reducing and others, which play a most important rôle in the transformation of various elements and compounds, aside from the above three general processes.

The plant population of the sea synthesizes, under proper light conditions, organic substances out of the simple nutrients, namely, the water, CO_2, available nitrogen compounds, soluble phosphates and other inorganic salts. The animals of the sea which are unable to utilize the photosynthetic energy of the sun must obtain their energy and materials necessary for the construction of their body substance from the plants, either directly or indirectly. Some lower animals, such as certain foraminifera, radiolaria, coelenterata and others, actually carry living algae which synthesize organic matter and thus serve for the nutrition of their host. After the death of the numerous plants and animals which inhabit the sea, their bodies as well as their excretion products are decomposed by bacteria living in the water, on the plankton or in the bottom sediments, as shown in the photographs.

DECOMPOSITION OF *ULVA LACTUCA* BY FUNGI, FOLLOWED BY ATTACK OF THE FUNGUS MYCELIUM BY BACTERIA.

Among the most important activities of the bacteria in the sea are the decomposition of plant and animal residues and the transformations of nitrogen. By decomposing the residues of marine plants and animals as well as their waste products, the bacteria return, in a mineralized form, to circulation in the sea, and in the atmosphere those elements from which the diatoms and algae inhabiting the sea synthesize their cell substance, namely, the carbon as carbon dioxide, the nitrogen as ammonia, the phosphorus as phosphate, etc. Without these actions of the bacteria, the sea bottom would soon become covered with a mass of dead plant and animal débris, and the limited supplies of available carbon (CO_2), of available combined nitrogen and of phosphate would soon become transformed into organic forms which are unavailable for growth of marine plants; this would result in cessation of plant life in the sea. In the process of decomposition of the residues, the bacteria themselves synthesize considerable cell substance, which may actually serve as food for various invertebrate animals and thus form a constituent part of the plankton of the sea.

Bacteria may also live symbiotically with various marine plants and animals. Among these symbiotic relationships, that of the green algae and the nitrogen-fixing bacteria has been suggested. In recent investigations carried out at the Woods Hole Oceanographic Institution, a close parallelism was found in the water and in the plankton between the abundance of diatoms and other plant and animal constituents and the numbers of bacteria. When the diatoms die, as shown by the rapid diminution in numbers, the bacteria still continue to develop at the expense of the diatom cells. This suggests the probability that the bacteria live in the free water only to a limited extent, but that they are largely associated with the plant and animal forms of the plankton, attacking

their excretion products, as well as the dead bodies.

Methods of Study of Marine Bacteria

Studies of marine bacteria have four distinct ends in view: (1) determination of the relative abundance of bacteria in the sea-water and in the sea-bottom material; (2) detection of the specific nature of the bacterial population, namely, the types of organisms that make up this population under the various conditions; (3) determination of the physiological activities of the bacteria isolated from the sea; (4) interpretation of the rôle of these bacteria in the cycle of life in the sea itself.

In the study of the occurrence, abundance and activities of bacteria in such a medium as the sea, in which they occur not in pure culture but as mixed populations, the methods employed are of considerable importance. These methods are both direct and indirect. In view of the small size of the bacterial cell, the relatively extreme dispersion of the bacteria and their comparatively low numbers in the ocean, any direct examination of the sea-water can tell very little concerning the occurrence and abundance of the bacteria; these cells should be concentrated, by removing much of the water, either by centrifugation, by filtration or by evaporation, before a microscopic examination is attempted. Most of the methods commonly employed in the past for the study of the abundance of marine bacteria were cultural in nature; here belong the gelatin and agar plate methods, the dilution method and the enrichment culture methods. Since no single medium will allow the development of all the bacteria present, even in a small quantity of sea-water or sea-bottom material, various media have to be employed. The early investigators limited themselves to counting bacteria by means of the plate method. At first the gelatin media were employed, soon followed by agar media, such as sea-water gelatin or sea-water fish extract gelatin and sea-water agar, with various modifications. It was recognized, however, at an early date that the sea contains many bacteria which are unable to develop on the culture plate. This led to the adoption of various dilution methods and specific enrichment culture methods. More recently there has been a tendency to use direct microscopic methods for the enumeration of bacteria both in the sea-water and in the sea bottom.

The plate method presents certain advantages but also various distinct limitations. The fact that one can determine the numbers of bacteria which are actually present in the sea in a living state, after they are allowed to develop on the plate, and the fact that one can isolate these bacteria from the plate for further study of their morphological and physiological characteristics are distinct advantages of the method. However, not all the bacteria present in the sea are able to develop on the common plate, some of the most important organisms, such as the nitrifying, sulfur-oxidizing, nitrogen-fixing, not developing at all; but even those bacteria that are able to grow on the plate will not all

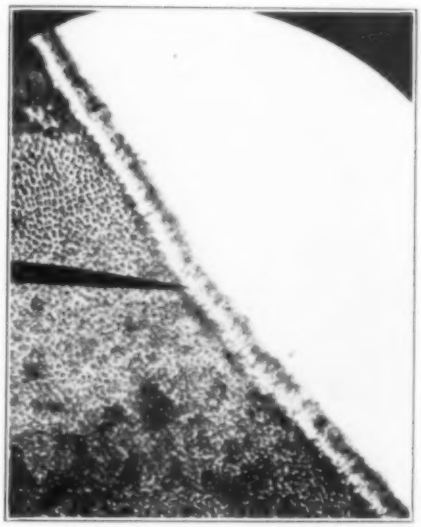
CROSS-SECTION OF *ULVA LACTUCA* SHOWING FUNGUS INVASION OF TISSUE; STAINED WITH HAEMOTOXYLIN AND CONGO RED.

develop and form colonies. The plate method may thus give an unbalanced picture of the bacterial population of the sea. To meet these objections, Cholodny and others suggested the use of a direct microscopic method. This method has certain advantages, since it gives a more correct picture of the abundance of bacteria in the sea; however, it does not enable one to distinguish the living from the dead bacteria or to separate the various types of organisms for further study of their physiological characteristics.

To determine the specific nature of the bacteria, the enrichment or elective culture method is usually employed; the sea-water or bottom material is added to a medium of specific chemical composition and the nature of the transformation brought about in the medium is determined. This method is very convenient for the purpose of demonstrating the occurrence of specific bacteria in the sea. By combining the dilution method with that of elective culture, the relative abundance of the specific bacteria can be estimated. This method was used for the purpose of demonstrating and isolating some of the most important bacteria now known to be found in the sea. The solution medium can be replaced by the silica-gel medium, which has found application in various investigations recently carried out at the Woods Hole Institution.[2]

No single method can be used for the study of the bacterial population of the sea as a whole. Various methods have to be combined in order to obtain an insight into the nature and abundance of this population. For the study of the abundance of proteolytic bacteria, the gelatin plate may be used, for agar-liquefying bacteria—the agar plate, for cellulose-decomposing bacteria—the silica gel cellulose plate, for demonstrating the presence of various other specific bacteria—various special methods have to be adapted.

[2] S. A. Waksman, C. Carey, and H. W. Reuszer, *Biol. Bull.*, August, 1933.



DECOMPOSITION OF *ULVA LACTUCA* BY BACTERIA IN SEA-WATER MEDIUM; THE EXTREME RIGHT SHOWS THE THIN GRANULAR FILM OF BACTERIA ATTACKING THE EDGE OF THE ALGA.

For study of the biochemical activities of marine bacteria, methods are employed which are based both on the nature of the organism and upon the specificity of the process under consideration. These methods are in most instances adaptations of methods employed in general bacteriology. The most important phase of the subject, however, namely the study of the rôle of the bacteria in marine transformations under natural conditions, has scarcely been considered at all.

Nature of the Bacterial Population of the Sea

Fungi are either entirely absent in the sea or are found at infrequent intervals. Whenever reference is made to their occurrence in the sea, a closer examination of the data will reveal the fact that this was due either to contamination in

MAGNIFIED SECTION

OF DECOMPOSITION OF *Ulva lactuca* BY BACTERIA, ×900; STAINED WITH HAEMOTOXYLIN AND CONGO RED.

the process of the preparation of the plates or to their chance infiltration from land and from dust (wind), especially at places close to shore. The fact that the genera Aspergillus and Penicillium occupy a prominent place among the fungi which were thus commonly reported adds further weight to the above conclusion, since these genera comprise the common dust and wind-borne fungi. One need not exclude, however, the possibility that fungi play a part in the decomposition of algal material and Zostera, when exposed to the atmosphere, as shown in the figures. Actinomyces are also either entirely absent or infrequently observed. Yeasts have frequently been found, especially certain Torulae, but their rôle in marine processes has been studied but little.

The bacterial population of the sea is quite characteristic. It is distinct in nature from the population usually found on land, as shown by the more limited number of bacterial types found in the sea. Spore-forming bacteria, which comprise an important part of the bacterial population in soil, are practically absent in sea-water, although they may be present in considerable abundance in the sea bottom. Cocci are also of limited occurrence in the sea. Motile rods and various types of vibrios, or comma-shaped organisms, usually make up the major part of the bacterial population thus far studied. The poverty of bacterial species in the sea depends largely upon the specific nature of sea-water as a medium for the growth of these organisms.

Certes observed in 1884 that only aerobic bacteria are present in the ocean; no anaerobic forms were noted. Bacteria were found to occur in the water to very considerable depths, namely, 5,100 meters. Fischer determined that, on an average, 1 cc of sea-water contains 1,083 bacteria, with a maximum of 29,400 and a minimum of 0. More bacteria were found in the winter than in the summer months. The marine bacteria were shown to be morphologically and physiologically distinct from the land forms, most of them being curved or spirilloid in shape.

In 1892, Russell demonstrated that sea mud contains greater numbers of bacteria than the above lying water: at a depth of 50 meters, there were only 121 bacteria in 1 cc of water, while 1 cc of mud contained 245,000 bacteria. Russell believed that the bacteria settle upon the mud in the form of spores or vegetative cells from the upper layers of water. The nature of the mud and its depth were found to influence the number of bacteria considerably. Most of these bacteria were proteolytic and were able to reduce nitrate to nitrite. According to Bertel, away from the coast in the open sea, the bacteria increase in numbers with depth. A marked difference in the numbers of bacteria in sea-water and in sea mud was also reported by Smith, Bavendamm and others. As many as 16,000,000 bacterial cells were

found in 1 gram of mud from the mangrove swamps of the Bahamas. Many of these bacteria were strongly agar-liquefying, pointing to their capacity of decomposing the organic complexes which are synthesized so abundantly by the algae in the sea.

In a recent study carried out at the Woods Hole Institution,[3] it was found that in ocean waters close to land and at sufficient depth to preclude agitation of the bottom by currents and wave motions, the numbers of bacteria are very small, usually not more than a few cells per 1 cc of water. The depth of the water and the nature of the sea bottom are of importance in this connection. Along shores receiving considerable land drainage, the numbers are much greater. The bottom deposits, especially the mud bottoms, are much richer in bacteria than the waters. A marked parallelism was found between the plankton organisms and the abundance of bacteria in the water, as well as a definite relation between the organic matter or humus content of the mud and the abundance of bacteria.

Among the specific bacteria commonly found in the sea, the nitrifying and denitrifying organisms have attracted particular attention. The formation of nitrates in the sea and their disappearance have aroused considerable interest. It was at first believed that the nitrates are brought into the sea from land or by atmospheric agencies. However, more recent evidence seems to point to the fact that nitrate formation is largely a result of bacterial activities in the sea itself. Thomsen and later Issatchenko, Lipman and others established the fact that, although nitrifying bacteria are not found in the surface waters of the sea, they can be readily demonstrated in the sea bottom. The investigations carried out at the Woods Hole Institution seem to point in the same direction.

As to the bacteria capable of reducing nitrate in the sea, one must avoid confusing nitrate-reducing bacteria with denitrifying bacteria: the first may reduce the nitrate only to nitrite and possibly to ammonia, while the latter break down the nitrate to atmospheric nitrogen or to gaseous forms of nitrogen. Although nitrate-reducing bacteria are present abundantly in the sea, denitrifying bacteria are found there but seldom, except possibly near shore or in the sea bottom. The results of Issatchenko, Butkewitch and those obtained recently at Woods Hole point in that direction. The mere fact that nitrite can be formed from nitrate by bacteria in the sea is no proof as yet that it leads to losses of nitrogen, since the nitrite can be assimilated by the phytoplankton organisms in their nutrition.

The presence in the sea of bacteria capable of bringing about the fixation of nitrogen has also attracted considerable attention. Benecke and Keutner were the first to isolate from the sea the aerobic *Azotobacter* and the anaerobic *Clostridium pastorianum*, the first organism occurring largely in the plankton and the second in the lower layers of water. Keutner, Keding and Issatchenko later demonstrated that Azotobacter cells are found on various algae growing in the sea; the same was frequently true of Clostridium and of accompanying bacterial forms. Reinke believed that a certain form of symbiosis exists between the algae and the Azotobacter, similar to that of the nodule bacteria and the leguminous plants. A typical culture of the aerobic, nitrogen-fixing bacterium, *Azotobacter chroococcum*, isolated from the sea-water, in the neighborhood of Woods Hole, is shown in the accompanying figure. Unfortunately, the importance of these organisms in ocean life has not yet been definitely established. Their occurrence in sea-water and in the sea bottom under different conditions, at

[3] H. W. Reuszer, *Biol. Bull.*, 1933. (In press.)

AZOTOBACTER CHROOCOCCUM

THE AEROBIC NITROGEN-FIXING ORGANISM, ISOLATED FROM THE SEA, × 1650.

different depths and at different temperatures, as well as the conditions influencing their activities, still remain to be determined.

Among the bacteria capable of bringing about the decomposition of marine residues, the agar-liquefying organisms, which are particularly abundant in the phytoplankton, have attracted considerable attention. These bacteria are capable of producing an enzyme which liberates soluble sugars from the complex carbohydrates which form the important constituents of the marine plants. The occurrence in the sea of cellulose-decomposing, of fat-splitting, of proteolytic and of various other bacteria has also been established.

Decomposition of Plant and Animal Residues and Transformation of Nitrogen

In order to understand the mechanism of the decomposition of the organic residues, it is important to know their chemical nature. Among the members of the phytoplankton in the sea, the diatoms are most abundant in the colder regions, while the Peridineae and the Schizophyceae are present largely in the warmer regions. The chemical composition of several members of the phyto- and zooplankton has been reported by Brandt as follows:

Chemical constituents, per cent. of dry material	Nature of organism		
	Chaetoceras	Ceratium	Copepods
Protein	10.0	13.0	59.0
Chitin	.....	.....	4.8
Fat	2.8	1.3	7.3
Soluble carbohydrate	22.0	39.0	22.5
Cellulose	0	41.5	0
SiO_2	54.5	.....	.....
Salt and other ash materials	10.7	5.2	9.2

In general, the organic carbon of the plankton is found to range from 14 to 48 per cent., the nitrogen from 1.5 to 10.6 per cent., and the ash from 13 to 65 per cent. The diatoms are richest in ash and lowest in nitrogen, while the zooplankton is low in ash and high in protein. Only the Peridineae contain cellulose, while the hemicelluloses form the most abundant group of carbohydrates among the diatoms and the various lower and higher algae. Fats are present abundantly, while the nature of the proteins still remains to be studied. It is of interest to note that 1 gram of dry matter in the plankton corresponds to 500,000 copepods, to 65,000,000 peridinia and to 675,000,000 diatoms.

It is of interest to compare the above analyses with that of a typical marine alga, namely, *Fucus vesiculosus* (see table on p. 47).

When the dead plants and the animals, their excreta, the various residues and degradation products undergo decomposition in the sea by the action of the bacteria, a number of organic and mineralized complexes are formed. A part of the organic substances may become soluble in the sea-water, while

Chemical constituents	Per cent.
Protein	5.4
Fat	2.3
Alcohol-soluble material	6.7
Cold water-soluble organic matter	13.6
Hot water-soluble organic matter	7.8
Pentosan*	28.7
Uronic acid anhydride*	27.5
Cellulose	3.9
Ash	13.9

* These two fractions represent largely the same chemical complex determined by two different procedures.

some of the residual substances as well as the synthesized bacterial cells may drop to the bottom and contribute to the formation of the marine humus.

The most important compounds formed in the process of decomposition of the marine plant and animal residues are ammonia, carbon dioxide and phosphates; the ammonia is oxidized by certain specific bacteria to nitrite, and then to nitrate. These compounds are thus made available for the nutrition of the marine plant population, namely, the phytoplankton and the algae. Raben and a number of other investigators demonstrated the fact that the deep water in the open ocean contains more nitrate and phosphate than the upper layers in which phytoplankton organisms are active; the North Sea waters contain more nitrate and phosphate in the summer than in the winter months. According to Brandt, the nitrate of the sea is continually renewed by rain and by rivers; he suggested that the denitrifying bacteria reduce the concentration of nitrates in warm regions, which thus accounts for the reduced phytoplankton production. Harvey concluded, however, that the introduction of nutrients from land into sea plays only a minor part, when compared with the quantity of nutrients formed yearly from the dead organic residues in the ocean itself. After death, the algae and the animal members of the plankton sink to the bottom and are decomposed there by bacteria, with the result that the phosphate and nitrogen are liberated in an available form. These mineralized nutrients are then brought to the upper layers by vertical circulation. The bacteria are thus recognized as playing a most essential function in the cycle of elements in the sea.

Organic Matter in Sea-Water and in the Marine Bottom

The question of the abundance, chemical nature and function of the organic matter found in the sea in an unorganized form, either in solution in the water or in a solid state on and in the

ZOSTERA
HEALTHY LEAF, SURFACE VIEW, × 600.

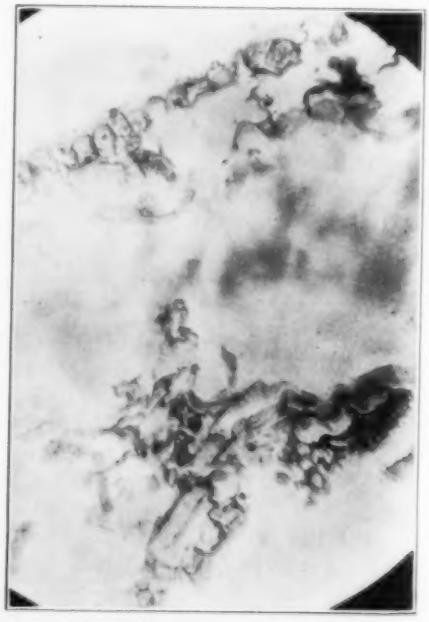
sea bottom, presents a number of highly important problems in which the activities of the bacteria play a prominent part. The function of the dissolved organic matter in the nutrition of the marine animals has been emphasized by Pütter. This theory was submitted to considerable criticism by Krogh and others. Pütter's figures for the dissolved organic matter in the sea were shown to be too high, and some of this organic matter was shown to be due to

ZOSTERA LEAF
AFTER 30 DAYS OF DECOMPOSITION, × 400.

the suspended bacteria, protozoa and unicellular plants present in the water. Although a part of the organic matter in solution may be liberated by the algae, there is no doubt that another part is produced by the bacteria in the process of decomposition of the plant and animal residues in the ocean.

Another source of organic matter in the sea is the marine bottom. This organic matter can be designated as "marine humus," because of its similarity in chemical nature, and probably in origin, to the humus found in soils. The concentration of this humus in the marine bottom varies considerably, namely, from 0.5 per cent. in the case of sand bottoms to nearly 10 per cent. in the case of certain mud bottoms. In some localities, such as protected harbors or fjords, the mud bottom may contain as much as 20 per cent. humus. This humus is best calculated from the organic carbon content, by the use of a certain factor. Boysen-Jensen suggested the use of a factor of 2, assuming that the carbon content of the humus is 50 per cent. However, a study of the chemical composition of the humus brought out the fact that this factor should be lower than 2, namely, 1.923, due to the presence in the humus of lignin-like complexes with a high carbon content.

One of the most important characteristics of this marine humus is its carbon-nitrogen ratio. Boysen-Jensen found this ratio to vary from 8:1 to 12:1, with an average of about 10:1. These results were fully confirmed by other investigators. When one recalls the fact that a similar ratio of carbon to nitrogen holds also for soils, the similarity of the marine humus to soil humus becomes even more apparent. Organic complexes similar to those found in soil humus can also be isolated from the marine humus. There are several reasons for the similarity: (1) a part of the marine humus is of terrestrial origin, being brought into the sea by streams and rivers; (2) the marine humus, just as the soil



ZOSTERA LEAF
AFTER ADVANCED DECOMPOSITION, × 400.

humus, is formed by similar microorganisms in a very similar manner. Certain differences observed in the chemical nature of the humus can easily be accounted for by the fact that marine residues, from which all or part of the humus is formed, are different in chemical composition from the land residues from which all the soil humus is formed.

The organic matter in solution in the sea-water as well as the humus in the mud are only slowly acted upon by bacteria; otherwise neither form of organic matter could be present in great abundance in the sea. However, even their slow decomposition is sufficient to provide a certain amount of available energy and nutrients for various bacteria living in the water and especially in the sea bottom.

Truly, the life of the plant and animal world in the ocean is variously dependent upon the manifold activities of the oceanic microscopic population composed principally of bacteria.

The author is indebted to Mr. C. E. Renn for the preparation of the sections of the marine plant material and to Dr. H. W. Reuszer and to Mr. C. E. Renn for the preparation of the photographs used to illustrate this paper.

Condensed Bibliography

W. Bavendamm, *Arch. Mikrob.*, 3: 205–276, 1932. W. Benecke and J. Keutner, *Ber. deut. bot. Gesell.*, 21: 333, 1903. R. Bertel, *Bull. Inst. Oceanogr. Monaco*, No. 224, 1912. P. Boysen-Jensen, *Rept. Danish Biol. Sta.*, 22: 5–39, 1914. K. Brandt, *Wiss. Meeresunters. Kiel*, N. F. 4: 213–230, 1899; 6: 23–79, 1902; 18: 185–429, 1916–1920; 19: 251–252, 1919. W. C. Butkewitch, *Trans. Russian Oceanogr. Inst.*, 2: No. 2, 1932. A. Certes, *Compt. Rend. Acad. Sci.*, 98: 690–695, 1884. N. Cholodny, *Centrbl. Bakt. Abt.*, II. 77: 179–193, 1929. G. H. Drew, Papers from Tortugas Laboratory, Carnegie Inst. Washington, 5: 15–191; *Jour. Mar. Biol. Ass.*, 9: 479–524, 1913. B. Fischer, *Centrbl. Bakt.*, 15: 657–666, 1894; Ergebnisse der Plankton-Expedition der Humboltstiftung, Lipsius & Tischer., Kiel and Leipzig, 4: 1894. H. W. Harvey, "Biological Chemistry and Physics of Sea Water," Cambridge Univ. Press, 1928. B. L. Issatchenko, "Récheréches sur les microbes de l'ocean Glacial Arctique, Petrograd, 1914. M. Kednig, *Wiss. Meeresunters. Kiel*, N. F. 9: 273–309, 1906. K. Kellerman and N. R. Smith, *Jour. Wash. Acad. Sci.*, 4: 400–402, 1914. J. Keutner, *Wiss. Meeresunters. Kiel*, N. F. 8: 27–55, 1905. A. Krogh, *Rapp. Proces-Verbaux. Cons. Intern. Expl. Mer.*, 75: 1–36, 1931. C. B. Lipman, Carnegie Inst. Washington, Dpt. Marine Biol., 19: 179–191, 1924. H. Molish, *Centrbl. Bakt.*, II. 65: 130–139, 1925. G. Nadson, "Microorganisms as Geological Agents" (Russian), St. Petersburg, 1903. A. Pütter, *Pflüger's Arch. Physiol.*, 204: 94–126, 1924. E. Raben, *Wiss. Meeresunters. Kiel*, 11: 119–132, 1910. J. Reinke, *Ber. deut. bot. Gesell.*, 21: 481, 1903. H. W. Reuszer, *Biol. Bull.*, to be published, 1933. H. L. Russell, *Bot. Gaz.*, 17: 312–321, 1892. N. R. Smith, Carnegie Inst. Wash., No. 344: 67–72, 1926. A. Thienemann, *Die Naturwiss.*, 13: 589–600, 1925. P. Thomsen, *Ber. deut. bot. Gesell.*, 25: 16–22, 1907; *Wiss. Meeresunters. Kiel*, N. F. 11: 1–27, 1910. S. A. Waksman, *Soil Science*, August, 1933.

MEAT RESEARCH IN THE UNITED STATES

By E. W. SHEETS

CHIEF, ANIMAL HUSBANDRY DIVISION, BUREAU OF ANIMAL INDUSTRY,
U. S. DEPARTMENT OF AGRICULTURE

An avowed purpose of meat research is to adapt the products of the stock grower to the changing needs of the consumer. Of equal importance is the problem of producing those preferred meats economically under the varied conditions prevailing in feed lot, range and forest. These aims are no different from those that obtain in other industries. Manufacturers all endeavor to develop a better product and to produce it more economically. Edison's carbon filament, incandescent lamp, revolutionary at the time, has long since given way to tungsten. Automobiles, tires, gasoline, roads and even traffic police must change to meet the changing needs of a changing world. Meat has changed too, particularly in size or weight of cut, but the hunt for a tender steak or a juicy roast is still a hunt in the minds of many consumers; too much a hunt for the satisfaction of either those who eat or those who produce the meat. Meat research is the effort of the live stock and meat industry to standardize its goods.

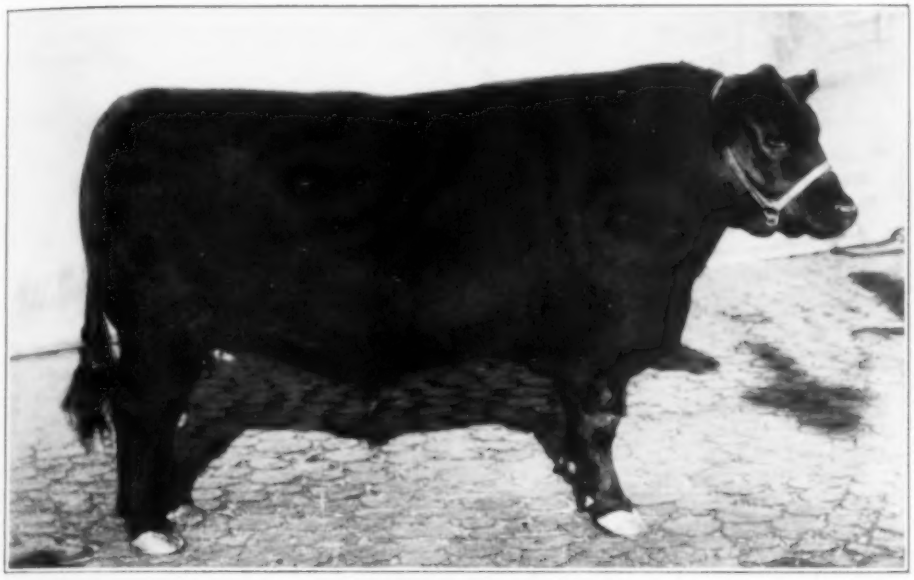
A third responsibility of meat research is to aid in the adaptation of live stock to current needs—a continuing adjustment that will give permanence, elasticity and soundness to the farming program of the nation. Live stock on grass offer to-day a solution to the problem of crop surpluses. Each acre of cultivated crop land converted to meadow crops and pasture will yield approximately half the live-stock feed it did before. Since 70 per cent. of the total quantity of harvested crops grown in the United States is fed to live stock, general conversion of crop land into pasture or meadow will result in less total live-stock production. The use of maximum quantities of pasturage and hay crops and a minimum of grains in live-stock production must not be done at the expense of quality, however. It is here that meat research is called upon to play an important rôle.

Meat research goes back to the first hunter who discovered that muscle from the back of his kill was more tender than pieces from the shoulder. The inventors of the first broiler (the forked stick), the maker of the first stew in a clay vessel, of the first cured ham, bring down the line of meat investigators to the tenderness comparisons of Lehmann in Germany before 1900, to the cooking studies of Grindley, Majonnier and others in Illinois in 1907, to the analyses of the food value of meat for the U. S. Department of Agriculture, by Atwater and Woods in 1894 and 1896, and Langworthy and others after 1900.

Contemporary meat research includes, among many projects, the efforts of Schmidt and his colleagues in Germany to develop strains of hogs with a greater proportion of lean to fat, and of the Danish cooperative organizations to improve, through both breeding and curing, the quality of Wiltshires which that country exports to England.

To Dr. Moran and associates in the Low Temperature Laboratories in Cambridge, England, we owe much for their study of the effect of freezing and storage upon meat shipped long distances. They have added to our meager knowledge of what meat really is.

Meat is a complex and, as yet, rather puzzling product. We have seen its general structure, noted its physical proper-



DESIRABLE BEEF TYPE

GRAND CHAMPION STEER AT ONE OF THE INTERNATIONAL LIVE-STOCK EXPOSITIONS.

ties and studied the composition of a number of substances found in it. Yet until recent years we have not been able to make definite comparisons of muscle to learn the effects of breeding, feeding and management upon palatability and food value. One recalls the definition of electricity given by the old high school physics teacher: "Electricity is a strained condition of the atmosphere in and around the thing electrified." Our definition of meat was almost as vague when this meat research was begun.

Eight years ago the National Live Stock and Meat Board, which represents all branches of the live-stock industry, called a meeting to consider the establishment of a cooperative meat research program. Representatives were present from the state agricultural experiment stations, the Institute of American Meat Packers and the U. S. Department of Agriculture. Organization was effected, a program adopted and each institution undertook those studies in which it was most interested and best equipped. Once a year the cooperators meet to present results, discuss methods and suggest advances for the coming year.

The plan of study was divided into three parts: Factors of production, of processing (storing, freezing, curing, etc.) and of cooking. Palatibility, food value and economy are the three measures used.

Cattle, hogs and sheep of various breeds, ages and sex are fed and handled under similar conditions. Various rations and methods of management are also compared. At the conclusion of the feeding or growing period the animals are slaughtered, chilled, cut, sampled and tested under comparable conditions.

Freshly slaughtered animals are chilled to 34° to 36° F. and held at this temperature for a standard length of time. Samples are then roasted by standard methods suited to the kind and cut. For example, every rib roast of beef is cooked to the rare stage, that is, until the meat at the center registers 62° C. as shown by a special meat thermometer. Hot

slices from these roasts are eaten and graded by a committee of five for aroma, texture, flavor, tenderness and juiciness. A cooked sample is also tested mechanically for tenderness in a power shear. Mechanical tests for juiciness are being developed.

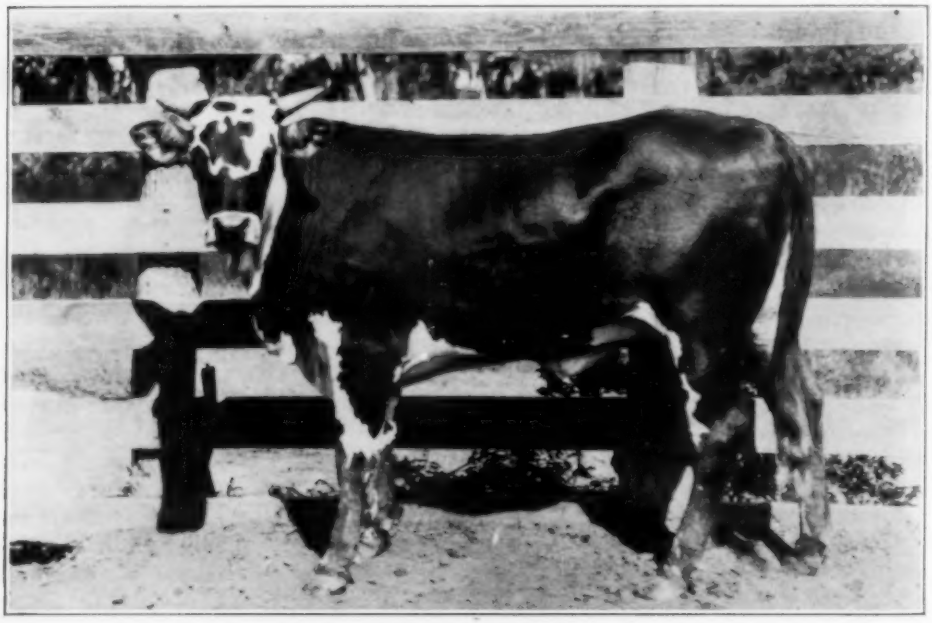
At the beginning of the experimental feeding period a grade or description of the conformation, character and fatness of the individual animals is recorded. The same is done at the close of the feeding period and after the carcass is dressed. These characteristics are then compared with the yield and palatability of the meat to determine the visible evidences of quality.

Physical and chemical analyses of carcasses, or of representative samples, give an accurate check on composition, particularly of fatness, as it relates to grade, yield, cooking losses, cooking time and palatability.

Quantitative determination of the content of the various proteins, connective tissues, enzymes and flavors have not yet developed to the stage where they can be applied. Neither has technique for a comparative histological examination been perfected. The relationship between composition and structure may provide a means for determining tenderness, flavor and juiciness more accurately than the methods now used.

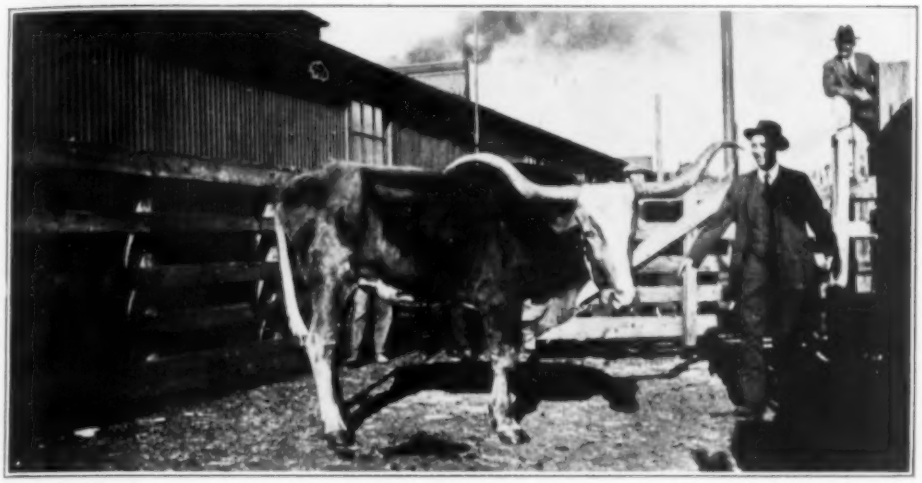
Another difficulty has been the individual variation in the inherent character of the experimental animals. There is more difference between individual animals in the same lot than between the averages of the two lots. We are forced to use larger numbers in each lot; to depend upon the law of averages to offset the error of individual variation until more uniform experimental animals can be produced.

The hope of obtaining more uniform



A BRAHMAN CROSS

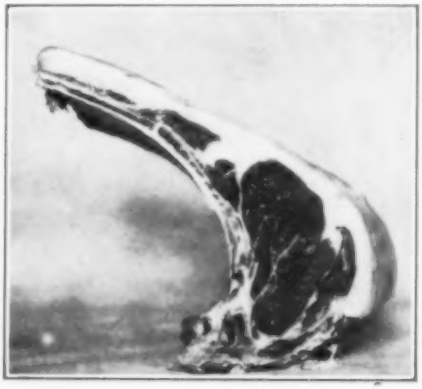
BRAHMAN BLOOD FROM INDIA HAS BEEN TRIED TO IMPROVE THE RUSTLING CAPACITY OF STEERS IN DRY, HOT, TICK-INFESTED AREAS.



THE LONGHORN OF TEXAS FAME
AMONG THE LAST OF HIS RACE.

experimental animals had its genesis in our first disappointment over the variation among steers of the same breed and age—steers that looked alike but performed differently. That disappointment made us think of other animal material which possibly might be better adapted to the working out of some of the complicated details which confronted us. Our minds went back to guinea-pigs upon which Dr. Sewall Wright, now of the University of Chicago, began extensive inbreeding investigations in the Bureau of Animal Industry more than 20 years ago. He started with 35 matings and continued by brother-sister matings. These families have been closely bred so long that, though only 4 of the 35 original matings remain, practically all variations in color, fertility, longevity and weight for age which are due to heredity have been eliminated.

LOW QUALITY BEEF RIB
CONTRAST SIZE AND SHAPE OF MUSCLES AND AMOUNT OF FAT WITH THE HIGH QUALITY BEEF RIB.



HIGH QUALITY BEEF RIB
THE FULL MUSCLING AND THICKNESS OF FAT LAYERS SHOW THE EFFECT OF BEEF BREEDING AND LIBERAL FEEDING.

CORRIEDALE RAMS

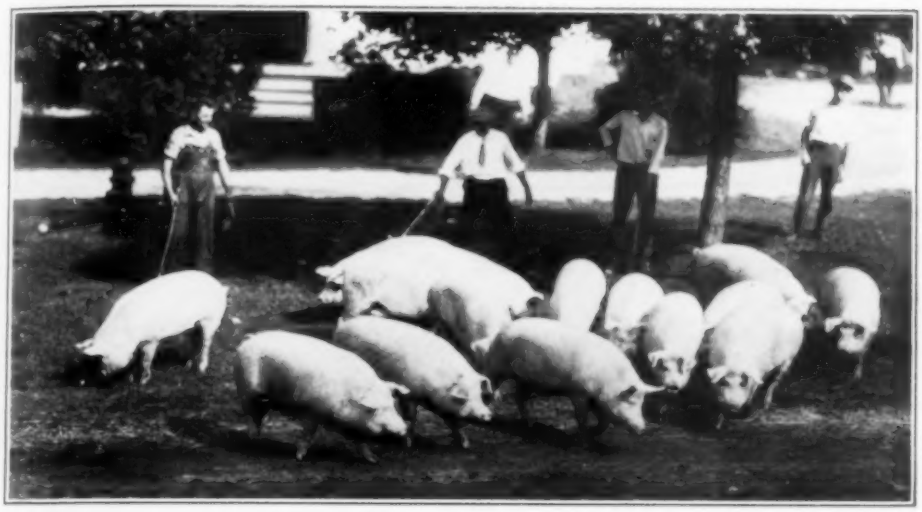
THESE EXCELLENT MUTTON SHEEP ARE BEING TRIED TO INCREASE THE WOOL CLIP OF LAMBS FROM NATIVE EWES.

From this work we now know that such characteristics as fertility, rate of gain and rate of maturity are influenced by inheritance. The principle has been applied in a similar system of breeding with hogs which have reached 6 generations of brother-sister mating. One strain of Chester Whites has not only maintained the quality and growthiness shown by the foundation stock but has actually shown improvement in these respects.

Studies on different breeds and strains within the breed utilize an increasing number of animals and amounts of feed. No state station is in position to maintain and feed the progenitors of several strains of cattle or sheep or hogs until progeny can be matured and tested. The Department of Agriculture, however, possesses, through transfer from the War Department, 56,000 acres of Montana range that was formerly Fort Keogh of frontier days. Adjacent to the department's 28,000-acre sheep station at Dubois, Idaho, are extensive mountain pastures made available to the experimental flocks through the Interior De-

COMMON TO CHOICE LAMB RIBS

NOTE DIFFERENCE IN SIZE AND SHAPE OF MUSCLE AND THICKNESS OF FAT.



A 2-TON LITTER

FOUR THOUSAND AND FIFTY (4,050) POUNDS OF HOGS FROM A SINGLE LITTER AT 6 MONTHS.

partment. Less expensive arrangements to maintain cattle and sheep would be difficult to make and the 30-odd members of our cooperative research program can look forward to the day when the problem of individual variation in experimental animals will be greatly lessened.

A product of this breeding work has been the discovery that strains or blood lines vary as to efficiency in the use of feed and desirability of the meat produced. Progeny of the different strains are fed and tested in what are called "record-of-performance" trials. For example, calves from selected matings of both beef and dual-purpose cattle are individually fed until they reach 900 pounds live weight. They are then slaughtered and their meat tested according to the regular procedure. The dressing percentage of 14 beef type calves ranged from 57.6 per cent. to 61.9 per cent. and the tenderness of their rib roasts from "moderately tender" through "tender" to "very tender."

Similar variation was also shown in the average performance of representative pigs from different litters. Handled under the same conditions the average daily gain of the 4 pigs selected to represent each of 12 litters ranged from 0.46 to 1.41 pounds and the feed consumed per hundred pounds gain from 360.7 pounds to 503.6 pounds. The yield of low-priced fat back varied as much as 2.9 per cent. and of the more-demanded ham 2.3 per cent. The superior lines are being preserved and crossed on the theory that mating the high values will produce, sometime, still higher values. We aim for uniformity in experimental stock. We hope, in addition, to produce pure strains of cattle, hogs and sheep that will make cheaper gains and yield still more tender, juicy steaks and chops.

Some of the facts already obtained from these meat studies are contrary to ideas and beliefs commonly accepted in the trade. One of the most striking deals with the color of the lean tissue of beef. Beef lean after being cut about one half hour is normally a bright, cherry red. Occasionally some steer or heifer carcass will show muscling of a

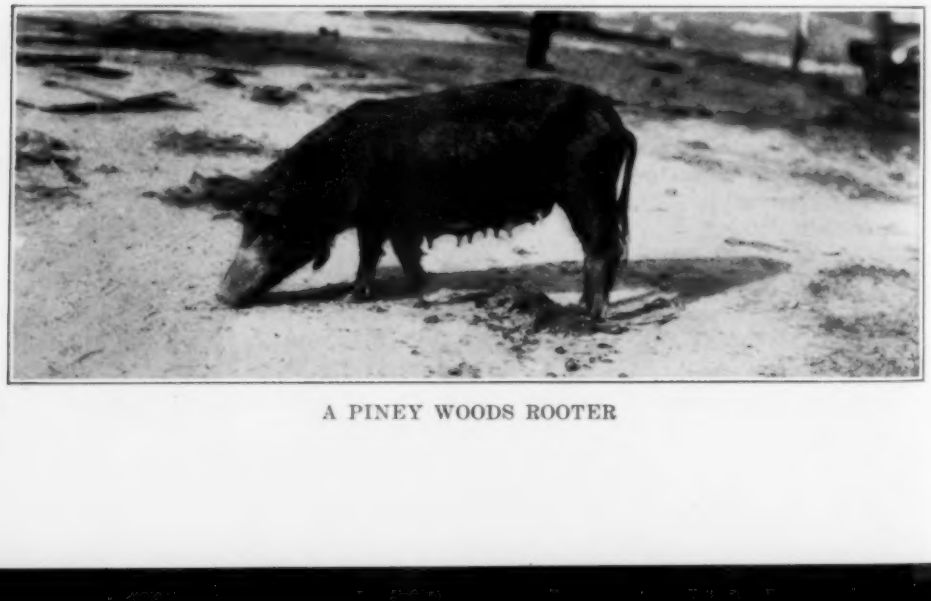
dark or almost blackish red. The cause for these "dark cutters" is as yet undetermined, but dark meat has always been classed and sold as tough and inferior regardless of its degree of youth, finish or conformation.

Our investigations have shown that dark beef is just as palatable and tender as bright beef of similar quality in other respects. In fact, after they are cooked, dark and bright beef can not be distinguished either in appearance or eating quality.

It is true that the beef from old cattle tends to be darker and may be lacking in tenderness, but to paraphrase and abbreviate the adage about the crow "all beef that is dark is not tough." We hope to discover and eliminate the cause of dark-cutting beef because it is unattractive and less appealing to consumers. That seems, however, to be its greatest fault.

Another point in which our results do not conform to accepted standards is in regard to fatness. The meat trade has always assumed that the more fat a carcass carried the better the meat. That is largely true. Amount of fat is a good guide to purchasers who are not familiar with all the indications of quality. Fat meat is usually "well-finished" meat. There are some exceptions to the rule, however. We will be able to give consumers more value for their money as we learn more about the effects of fattening on tenderness, flavor and juiciness. Our results with three-year-old steers fed grass alone, compared with those fed grass and a supplement of grain, is a good illustration. The steers fed grain were heavier, fatter, more attractive, and dressed a higher percentage of carcass than those given only pasture. The rib cuts from the grain-fed steers analyzed 38.5 per cent. of fat, those from the other lot only 30 per cent. The standard rib samples used for cooking averaged 12.5 pounds in weight from the fatter steers and only 10 pounds from the thinner cattle. Here is where the consumer becomes interested! The 10-pound ribs contained just as many pounds of lean and protein as those weighing $2\frac{1}{2}$ pounds more and no more bone. In other words, the food value of the ribs, excepting for the fat, was just as great in ribs that would have weighed less and cost less to buy. The palatability of the two sets of ribs was very similar. The additional fat did increase slightly the richness of the juice, but the difference was too small to offset the extra cost of those heavier ribs.

Thinly fleshed cattle and lambs have given the poorest flavored meat that we have handled through the laboratory. In contrast, among the best, if not the best, beef was from six show steers, all



A PINEY WOODS ROOTER

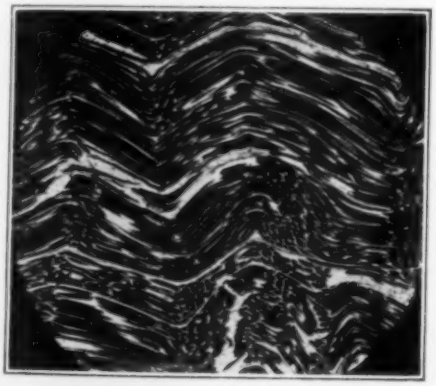
of which carried a so-called "wasty" finish. Our facts are too few to warrant a definite statement as to the degree of fatness that will give the product the greatest consumer value. Results to-day indicate, however, that, although increasing fatness is desirable, it can, under some conditions, cease to be a virtue and become another "surplus."

A brief summary of some of the other results already obtained illustrates the breadth and purpose behind the research program that is being conducted by these cooperating state and national organizations.

Neither breed nor character of ration, as far as the studies have been carried, has been found to cause significant differences in the palatability of meat.

The chief disadvantage of well-fed lambs and calves produced by "scrub" instead of "improved" breeding appears to be in the weight, dressing per cent., attractiveness and storage adaptability of the carcass rather than in the palatability of the meat.

Heifers fatten more quickly than steers, but the meat from the two sexes is similar in palatability when other conditions are equal.



PHOTOMICROGRAPH OF BEEF MUSCLE

SHOWING BUNDLES OF MUSCLE FIBERS, CONNECTIVE TISSUE AND FAT. IT IS WITH VARIATIONS IN THE ARRANGEMENT AND CHARACTER OF THESE CONSTITUENTS THAT SOME MAJOR PROBLEMS IN QUALITY OF MEAT ARE CONCERNED.

ROASTED EXPERIMENTAL LAMB LEG

STANDARD SLICES ARE CARVED FOR TESTING BY THE GRADING COMMITTEE.

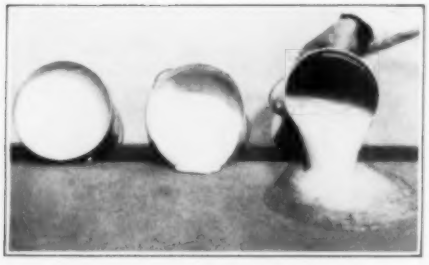
Corriedale rams have improved the quality of wool production in Hampshire type native ewes without decreasing the mutton quality.

Suckling lambs on good pasture made just as large gains and produced just as desirable meat as similar lambs fed grain in addition to grass and mother's milk.

Wheat produced as large gains and as firm and palatable pork as corn.

Soft and oily pork produced by feeding peanuts to the hogs was practically as desirable in flavor and aroma of the roasted fresh meat as firm pork produced by corn-fed hogs.

Processing problems deal with methods for handling meat after the animal has been dressed. The task is to take the animals that the stockmen have produced and present the meat to the consumer in its most palatable, economical and merchantable form. Methods of chilling, cutting, curing and ripening are of first importance—chilling to keep the meat wholesome and attractive; cutting to divide the muscles so that each patron can secure just the weight and quality



HARD, SOFT AND OILY LARD
DIFFERENCES IN FIRMNESS WERE DUE TO RATIONS FED.

needed for broiling, roasting or stewing; curing and ripening to develop the maximum flavor and tenderness inherent in the meat.

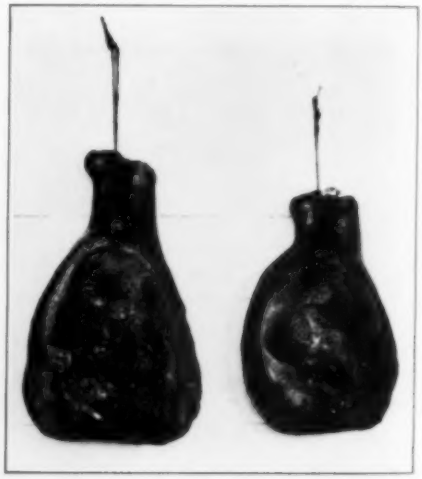
Adaptations of refrigeration units have been devised to meet the needs of farm communities and of individual farms and plantations. A decrease in the spoilage of farm-cured meat and an increase in its palatability have resulted.

Cutting meat so that the muscles will be divided in a manner that provides cuts suitable for small families is a move in the direction of more complete utilization of meat. The National Live Stock and Meat Board has pioneered in this work among commercial meat retailers.

A search for milder, more desirable cures for farm-cured meat, and rapid cures for commercial meat, the retention of mellow succulence in aged hams and a study of the adaptability of cured lamb and mutton to the farm and to commercial markets have been the chief activities along the curing line. A more detailed study of bacterial action in relation to temperature and the palatability of cured meat is now being made.

Ripening fresh meat consists in hanging it in cold storage for such length of time as will permit the enzymes and other autolytic agents to hydrolize the tissues and develop flavor. We have found that lamb legs make much more tender roasts after a storage of 7 to 10 days than if eaten within the first week after the lambs were slaughtered. Longer ripening than 10 days did not improve them materially. Well-finished beef is often ripened for six weeks, but our studies have not been complete enough, as yet, to determine the respective merits of short and long aging for beef. These ripening experiments offer a fertile field for possible improvements in the palatability of meat. The chemist, physicist, histologist and bacteriologist will probably be able to show us how to increase materially the desirability of meat from animals that have not had the advantage of optimum feed conditions.

Coupled with the palatability and food value of meat is economy of preparation and serving. Home economics workers are studying the problems of cooking time, cooking losses, fuel consumption and number of attractive servings in relation to the kind and cut. These workers have shown that by controlling oven temperature and keeping it moderate most of the time they can actually cut down the cooking losses by a pound or so on a 10-pound roast. Fat



"SHANKY" AND WELL-MUSCLED HAMS
DIFFERENCES IN LENGTH AND THICKNESS ARE DUE TO BREEDING.

meat roasts more rapidly (minutes to the pound) than lean. Boning and stuffing such cuts as shoulder of lamb or pork converts them into delicious roasts easy to carve and economical to serve. A more complete detailed study of the effect of heat on meat will follow the development of better technique in chemical and histological comparisons.

Much has been learned by various investigators about the part meat plays in promoting growth and health, and preventing disease; the value of its complete proteins, its minerals and vitamins, the effect of its palatability upon digestive processes, the value of lean meat in preventing pellagra, the value of liver in preventing anemia. We hope to fractionate still further these complex substances so that meat and products of meat can be of greater service to all.

The cooperation between the many state and national laboratories in meat research is a "result" that I mention last in order to give it emphasis. I know of no finer example of concerted effort than this work gives. We have had to pioneer, to reach beyond the known in both subject-matter and method. New discoveries, new ideas or even "hunches" have been made common property to the advantage of all. We serve a great branch of agriculture. We have much to do. We can do it better and more quickly through cooperation.

DEFOLIATION ACTIVITIES OF GRAY SQUIRRELS IN AMERICAN ELM TREES

By Dr. CARL G. DEUBER
ASSISTANT PROFESSOR OF PLANT PHYSIOLOGY, YALE UNIVERSITY

EACH spring a shade-tree drama of considerable interest is enacted within a hundred feet of my office windows on a university campus, and it is one that may be observed throughout all New England and wherever the gray squirrel finds life feasible in the vicinity of American elm trees on well-kept lawns. The situation has to do with the gray squirrel making his entire diet practically of elm seeds during the latter part of May and in early June. These seeds are of little consequence to the tree or to man in that they are produced in abundance and the reproduction of elm trees by seedlings is a relatively simple matter. But this situation becomes a shade-tree and a lawn problem when the squirrel's habit of eating this delicacy is examined—and not necessarily closely.

As the elm seeds ripen in the latter part of May the gray squirrel scampers out to within six inches of the ends of even the smallest branches, eats a few seeds out of the seed cluster on that particular branch, then quickly reaches out to the seed cluster of neighboring branches. These are usually inconvenient to eat from that position, so he draws the twig to his mouth with a fore paw and nervously bites it off in the midst of the seed cluster. After stripping off most of the seeds or merely slitting open the papery covering over the kernels of attached seeds and deftly

LAWN AT FARNUM GARDEN, YALE UNIVERSITY,
LITTERED WITH ELM TWIGS CUT BY TWO PAIRS OF SQUIRRELS. MAY 27, 1933.

extracting the rich, oily kernels, he allows the twig to float to the ground. Since these twigs have fresh new leaves a tree health problem is presented in which it becomes desirable to evaluate the effect of this defoliation on the well-being of the shade-tree. And since the leafy twigs must necessarily land on the lawn a problem in maintaining the lawn free of this leaf litter is presented to the yardman. This does not mean that the matter is one of tragedy, necessarily, but one certainly worthy of examination.

Before analyzing the tree problem it must be emphasized that the gray squirrel is a package of energy and industry. These traits bring him under surveillance as a pest in more than one respect. Several squirrels were timed on their twig-cutting activities. One individual was chewing off three twigs per minute, another pair kept five and seven twigs floating down in the air in the course of two respective minutes. The gray squirrel loses time only when a new feeding position is taken. Toward the end of the seed crop the squirrels will work even the outermost branches, fifty feet or more from the ground, giving the appearance of furry plummets.

Since this feast of the squirrels on elm seed comes at the season when a professor's time is a trifle more his own than during the winter period, due to the ancient invention of final examinations, it was decided that this year the squirrels would be held to an accounting for their spree on my favorite tree. Morning and evening for five days during the midst of the twig-cutting lark the task of collecting and tabulating the damage was self-assigned. On the first day the twig crop reaching the lawn amounted to 517 items. This was calculated to represent 2,585 leaves having a surface area of 75 square feet. This leaf area, a little larger in size than an 8 by 9 rug, was laid low by two squirrels in one tree. The next two days were cloudy and rainy and the leaf carpets were

YOUNG SQUIRRELS FEEDING UNDER A "FAVORITE" AMERICAN ELM TREE ON A YALE UNIVERSITY CAMPUS. JUNE 8, 1932.

LITTER OF THREE YOUNG SQUIRRELS OCCUPYING A BIRD HOUSE IN A ROSE ARBOR AS A NEST. MAY 26, 1933.

approximately 7 by 9, but on the fourth, a hot, sunny day, these squirrels were hungry and industrious, for they eliminated 892 twigs with a leaf area of 131 square feet—a 10 by 12 rug with a margin. Incidentally, 312 linear feet of twigs had held these leaves in the sun. Although data were taken for only five days, the seed-eating and twig-clipping covered a period of ten days—it ceased when the seeds gave out. It is conservatively estimated that more than 500 square feet of leaf surface were chewed off this one elm tree by two squirrels.

Up the hill at the botanical garden a beautiful, large, isolated American elm was found supporting two pairs of gray squirrels. The tree had been sprayed with arsenate of lead during the week, but this did not deter the squirrels. At nine o'clock one morning the lawn at the foot of this tree was literally covered with elm twigs cut the previous day and on this morning. A count revealed 2,886 twigs, 14,430 leaves with a leaf area of 421 square feet. A rug 20 by 20 would fit quite a large living room. This tree probably had 1,000 square feet of leaves eliminated this spring by the two pairs of squirrels.

The meaning of this defoliation of elm trees in terms of the health and vigor of the tree bring forth speculations which demand reflection rather than hasty judgment. Trees suffer from and are benefited by defoliation, depending on a variety of factors. Trees are sprayed annually to prevent the devastating effects of insects, such as the elm leaf beetle. The orchardist must follow a more or less rigid pruning program in order to encourage and maintain fruitfulness, and the nurseryman trains and shapes his tree stock with specific objectives in mind.

Defoliation, irrespective of its extent, eliminates food-manufacturing organs from a tree. By using a conservative figure for the rate at which dry matter is synthesized by green leaves active six hours a day and during ninety days, some basic data for further discussion can be obtained. Five hundred square feet of leaves would have the capacity

to synthesize over 1,200 pounds of dry plant material. If an elm tree has a million leaves the elimination of 500 square feet of leaf surface would decrease that tree's potential capacity by approximately 2 per cent. But if there were but one half this number of leaves and the defoliation was to the same extent, then the reduction in food and tissue manufacturing would be 4 per cent. This latter value is suggested as the probable reduction in the synthetic powers of the first elm tree described earlier in this article. The true significance of the damage done this tree by one pair of squirrels in the spring over this or many years by the elimination of healthy foliage is practically impossible to state. But there are other considerations.

The American elm is naturally found growing in rich alluvial soil and prefers moist bottomlands. It is further characterized by an extensive and shallow root system. The natural environment of the American elm is not frequently encountered on a lawn or along a city street, so that the planted tree often shows the effect of a lack of sufficient water during midsummer. Although the roots may be firmly established and

ELM TWIGS IN BASKET, 198 IN NUMBER, REPRESENTING ONE MORNING'S TWIG-CUTTING ACTIVITY OF ONE PAIR OF SQUIRRELS. ALSO TYPICAL ELM TWIGS CUT IN THE MIDST OF THE SEED CLUSTERS. MAY 23, 1933.

ELM SEEDS

THE FOOD THE SQUIRREL SEEKS IN ELM TREES DURING THE LATE SPRING. MAY 23, 1933.

of great extent, the foliage is so constructed that water, as vapor, is lost at a more rapid rate from the leaves than the roots can secure it from a relatively dry soil. One remedy is to adjust the extent of the foliage surface to the capacity of the roots to supply water. The defoliation by the gray squirrel may therefore be a real benefit in helping to establish a more suitable ratio between the leaf area losing water and the capacity of the roots to supply water.

The brief feeding period of the gray squirrel upon elm seeds, which involves an appreciable defoliation, can be looked upon as about as beneficial as destructive so far as the well-being of the tree is concerned. Observation indicates that the gray squirrel seeks the most vigorous American elm trees in his vicinity—obviously for the abundant seed crop they bear. The worst score against the gray squirrel is the nuisance he creates by daily littering otherwise well-kept lawns with leafy twigs. The expressions of several yardmen on this point are not complimentary to the squirrel. But so long as natural laws prevent the gray squirrel from becoming too numerous, we can perhaps share our elm trees with them during the brief period when they find elm seeds fit their dietary requirements without worrying too much about the damage they are doing to the trees.

THE TENNESSEE VALLEY AUTHORITY[1]

By Dr. ARTHUR E. MORGAN

CHAIRMAN OF THE TENNESSEE VALLEY AUTHORITY

THE proper way to treat the Tennessee Valley Authority is not as an isolated undertaking, but as an integral part of the whole program of the present administration. Most of the great and enduring loyalties of men are loyalties to broad and inclusive generalizations. The dominant religions of the world are examples. They undertake to provide explanations of the purpose and nature of existence and to set up a way of life that will bring about the fulfilment of its greatest possibilities. In the Russian program, broad, sweeping conclusions about life and society provide a justification for sustained enthusiasm and for great sacrifice.

There are few cravings of men so strong, so persistent and so deep as the craving for an inclusive philosophy, an all-embracing purpose. No leadership which does not provide these can long endure. A promise of obvious and immediate benefit may bring quick and overwhelming response, but for any movement to be long significant, it must undertake to deal with the very nature of things and must offer guidance in the solution of the fundamental problems of living.

A long range reading of history will, I think, support this statement. Yet, men are almost universally suspicious of new generalizations. After any view of life has won its way to acceptance, it is taken by the mass of the people to be just a part of things as they are, as is the climate. Let any new generalization appear, no matter how logical and inevitable it may be, and it is met with suspicion and incredulity. One reason for this is that the average man, while he craves an inclusive philosophy for his life, feels intuitively that he is not equipped to critically appraise the soundness and representativeness of any sweeping generalization, and that he should resist it until it is supported by adequate authority. That authority may be an overwhelming emotional appeal, or it may be the support of able men, or it may be evidence of practical capacity on the part of those who make the affirmations. Men do well in refusing to accept a generalization until they have evidence that the person making it has practical ability in the particular field involved, for conclusions about the world and about life are efforts to interpret the nature of things, and should have no claim to authority except as they come from men who have actual acquaintance with and understanding of things, people and events.

But right here we meet with a dilemma. The average man often endeavors to judge the merit of long-range generalizations by temporary and partial results. Sometimes his range of vision is shorter than the necessary periods with which the generalizations deal. To illustrate, let us take the case that is most familiar, the beginning of Christianity. The great Teacher had made sweeping declarations about the nature of human life and about the qualities and attitudes that should characterize the social order. He repeatedly stated that this new order could be the result only of patient search, great commitment and of slow and gradual growth. He repeatedly

[1] Address to the National Academy of Sciences, Massachusetts Institute of Technology, Cambridge, November 20, 1933.

protested that His teachings were being judged, not by their inherent worth, but by "signs and wonders." "The people seek for a sign," He said. He felt that many followed him for the loaves and fishes and not because he proposed a better order of society. Those who presented His philosophy and His personality to the world after His death did not trust to the survival of that philosophy on its merits, but surrounded it with the support of "wonders and miracles."

When we come to appraise the merits of broad-scale conclusions about men and about the social and economic order, it is only with great difficulty that we can weigh and appraise the real knowledge of the nature of things, and the insight, acumen and judgment, which have entered into the making of them. Sometimes we seem compelled to rely upon superficial evidences of practical ability, which may have little to do with the soundness of the generalizations.

I believe that the program of President Franklin D. Roosevelt is more than an assemblage of political and economic expedients. I believe that President Roosevelt has an inclusive social philosophy that has a large degree of clarity, order and integration. To me that philosophy seems to be unusually reasonable, sane and human. It seems to me to be radical in that it gets beyond temporary expedients to elemental issues, and it seems humane and reasonable in its endeavor to bring about necessary changes without violence or undue upheaval which, while establishing a new pattern of society, might do so at tremendous present loss.

Although ours is a young country, our habits of social and economic life are very deeply impressed upon us. To make significant changes in these habits, and to actually lay the basis for a different social and economic order, is no short-time job. Deeply worn paths of habit and action must be cut across with new highways. The period of reconstruction will be troublesome and inconvenient. In Boston here, a few well-planned, broad main highways through the heart of the city would enormously relieve congestion and bring order and economy in local transportation. Yet if that should be undertaken, the temporary inconvenience would be very great, and if those whose vested interests should be interfered with should use that temporary inconvenience to discredit the project, they might be quite successful. In my opinion, a temporary dislocation of things-as-they-are will be an inevitable accompaniment of any significant improvement in our social and economic order. Yet a large number of people will judge the merit of any undertaking solely by its immediate effects. If these people predominate, then the chance for the success of a program will depend, not upon its intrinsic merit, but by the capacity of the leader to produce "signs and wonders" for the benefit of those who judge by immediate and incidental results. I scarcely need list the "signs" which the American people would accept as adequate proof of the authenticity of the President's leadership. Two-dollar wheat, a sudden reduction of unemployment, resumption of dividends, reduction of retail prices —all these would be authentic "signs."

You are wondering by this time what all this has to do with the Tennessee Valley Authority. I believe that my introduction is not irrelevant. A part of the President's program must of necessity be on a national scale. Tariff policy, banking policy, the National Recovery Administration, these and other issues must be dealt with by the nation as a whole. But in the effort to bring social and economic design into our national life, there are many issues which can best be worked out on a limited scale before they are given national application. Many of our problems have regional

variations, and can best be solved through regional interpretation. To provide a limited area in which some of those national issues would have consideration, the President proposed, and the Congress established, the Tennessee Valley Authority.

When I first became acquainted with the Tennessee Valley Authority Bill on its way through Congress, I was greatly disappointed. Here was a great project in social and economic planning, and yet a very limited opportunity was offered for demonstrating the practical competence in handling affairs which to so large a degree is the basis for public confidence. The principal construction work within the area was to be put into other hands, and the Authority itself was at first to have relatively little to do with a construction program. I feared that unless the Tennessee Valley Authority should be more deeply engaged with practical matters than the provisions of the bill allowed, its prestige might not increase very rapidly, for there would not be adequate opportunity to demonstrate practical competence. I therefore sought successfully to have the bill changed so as to give the President greater range of choice in deciding what organization should handle the major construction to be undertaken in the region.

When the law was enacted, the President was requested to place the building of the Norris Dam, which was by far the largest item of construction work, in the hands of the Tennessee Valley Authority, rather than in the hands of one of the other departments mentioned in the act. This was done in order to provide practical activities by means of which the Tennessee Valley Authority could become known to the people of the region as a competent administrative organization. With this construction committed to the Tennessee Valley Authority, it became necessary to develop a well-designed administrative organization and to enter vigorously on a construction program.

A little more than five months have elapsed since the directors of the Tennessee Valley Authority were appointed and confirmed by the Senate, the necessary appropriations passed and the corporation organized. As this was a new type of organization under the sun, with a board of three directors who were strangers to each other, and since every point of policy and program and every relation to the administrative processes of government had to be developed, some time necessarily was consumed in getting our bearings. A power program, a program for the development of fertilizers and a general program of planning had to be formulated, as well as an immediate construction program.

An excellent administrative staff has been assembled, after an exceptionally painstaking search, and is well adjusted to its functions. The Norris Dam, the largest construction project of the Tennessee Valley Authority, is well under way, with 1,500 men employed, about as many as will be used at the peak of construction. I believe that less than 5 per cent. of the public works projects of the present administrative program have made as great progress in organization, design and construction. When recently we were unexpectedly asked to undertake the construction of another large dam, this time across the Tennessee River, that additional work was taken on as an almost routine matter, and construction was begun in about one month. The entire administrative staff is now well integrated and well adjusted to its immediate practical job. We have recently informed the Emergency Relief Administration and the new Civil Works Administration, that we can, if needed, quickly expand our staff to supervise the employment of twenty-five thousand or fifty thousand men on emergency projects.

The power program of the Tennessee Valley Authority has been worked out under the direction of David E. Lilienthal, a member of the board, with vigor and dispatch and, I believe, in a masterful manner. The first contract for furnishing power to a municipality has recently been executed, and several hundred miles of transmission line will shortly be under construction.

The fertilizer program of the Tennessee Valley Authority, which was explicitly provided for in the law, also is well under way, directed by my colleague, Dr. H. A. Morgan, with an excellent research staff. Pilot plants are being designed and will shortly be under construction.

During this period about one hundred and ten thousand applications for positions have been received. About sixty thousand of these have been classified and rated so that the best prospects can be quickly located in any field. Another fifty thousand applicants will have been given examinations and will have been classified and rated by mid-January.

A number of acute issues have been met and faced. For instance, there is the matter of patronage and the spoils system. The Tennessee Valley Authority law provides that all appointments shall be made on merit and not for political considerations. It is my personal opinion that the President approves this provision. Yet the issue of spoils and patronage has been met very acutely. The record of the Tennessee Valley Authority on that issue should, I believe, give confidence to those who hold that public servants should be chosen for their merits and not because of political influence.

Those who are administering the Tennessee Valley Authority have, I believe, given evidence that they have had some contact with realities and some acquaintance with public and business administration. With that demonstration, we hope that we may achieve some other classification than the Washingtonian designation of "perfesser" in our effort to work out a program of social and economic planning in cooperation with the people of the Tennessee River region.

What should be the aim of such planning? Considering the Tennessee River region, not as having peculiar and different problems, but as being representative of many regions in America, what do we find? We have in this region a population of old American stock with a large proportion of persons of good intelligence. A large industrialist, who has plants in various parts of the country, tells me that nowhere else does he find so large a proportion of his working force made up of men who can understand and master technical processes and problems. The working forces on our construction jobs are of a higher order than we commonly find in other parts of the country. About twice as many people are engaged in agriculture as are necessary to till the soil. Good roads have opened up the region and made accessible areas that formerly were remote and isolated.

Mineral resources in this region are exceptionally abundant and highly diversified. There are large deposits of coal. Much of the hardwood timber has been cut and exported from the area as raw material, but there is still an adequate supply for local industries which will produce finished goods. Climatically, this is one of the favored regions of America. The few localities, like Asheville, which have become known as fall and spring resorts, are but typical of large areas. The summers are not too hot, or the winters too cold. There is an abundant water supply, in many localities exceptionally free from iron, lime or other minerals and therefore suitable for exacting manufacturing processes. Lastly, there is a great reservoir of po-

tential power. About 3,000,000 kilowatts are awaiting development, at unit costs that in many cases are very favorable.

We seem to have here all the factors for a prosperous, progressive community, and yet we find production and consumption on a low level. The Tennessee Valley Authority area varies greatly in different parts. In the northeast portion are localities where, until ten years ago, many young men and women had never seen a colored person. On the other hand, along the southern boundary of the area are counties where a quarter to a half of the population is colored. The Tennessee River region contains some notable, progressive and well-kept farm communities and some prosperous cities.

Generalizations must not be carried too far in so varied a region, yet it is true in general that only a very small part of the potential productiveness is being realized. One study of a mountain county in Kentucky indicated that the average cash income of a mountain farm is $45 a year. A study of 200 mountain farms in Western North Carolina, distributed in four localities, indicated that the average cash income, after paying fixed charges, such as taxes and fertilizer, is $86 a year. A large part of the farms of the region have a cash income of less than $250 a year after taxes are paid.

Here we have the picture—a vigorous and intelligent people near the center of the American population, abundant natural resources, a great reservoir of cheap power, a fine climate—but a low level of production and consumption and relatively little effective social and economic organization. The region is not yet heavily committed to mass production and economically is still in flux. Only a quarter of the population lives in towns of 2,500 or more. To a large degree in the past, the industry of the region has consisted of the exploitation of natural resources, to be exported as raw materials. More recently it has turned to the exploitation of cheap labor.

This is the region the President has selected for a case in social and economic planning. Given a magic wand, these factors could be turned into prosperity, well-being and wholesome culture. But magic wands are not quoted on the market. The President, I believe, sees this project as one of seeking the cooperation of the region in eliminating the grossest wastes and in creating design, order and organization for releasing the creative capacities of the people and for the best use of the natural resources of the region. Let us outline some of the major wastes, present and potential, which reduce well-being.

First, there is soil erosion. In the rolling lands of the Southern states this issue is far more critical than in the North and West. Millions of acres have been entirely destroyed for agricultural use. Deep gullies extend every year further into the fields, and each year the hillsides of bare clay, from which all loam has washed away, increase in area. Unless this process can be stopped, the human culture of considerable regions will disappear. When a large part of an area is destroyed for agriculture, the remainder can scarcely afford the necessary taxes for schools, and the better families move away. After that the destruction is accelerated.

There are several possible methods for stopping this waste. Terrace farming and careful management of the soil may reduce the erosion to less than a quarter of its rate on badly managed farms. Crops which keep a sod over winter can be planted instead of corn, for which ground is plowed in the fall and exposed to washing all winter. Certain new pasture and forage crops are very promising. The hilliest lands should be taken

out of cultivation and planted to forest. Finally, the laws of land ownership should be changed so that men shall not be allowed to own and occupy land unless they will manage it in the interest of a permanent agriculture. Such a legal change would constitute one element of a social revolution.

Then there is the great waste in the electric power situation. Men have a few basic needs which must be supplied as part of a civilized environment. One of these is an abundant supply of pure water. Other basic services are transportation, communication and power. We shall steadily approach the time when these services are so cheaply and abundantly supplied that they fall into the background as requiring but little of our thought.

At the present time electric power is one of the live issues of social planning. Every one is familiar with the disclosures of the Federal Trade Commission, of the wide-spread endeavor by secret and open propaganda to control the thinking of the nation on this issue. In a few cases where unusual indiscretion has opened the scene to the public, as in the case of the once very honorable Mr. Insull, we can see what the industry is like on the inside.

The Tennessee Valley Authority is interested in the electric power issue on several counts. First, if a case of public ownership and operation can be established, with fully open and comparable cost accounts and records, we may be provided with a "yardstick" by which we may discover what electric power actually ought to cost. The private utilities, if they are sincere in their expressed belief of the superiority of private ownership and operation, should welcome such an example.

It is not only the private utilities that will be provided with a "yardstick." Public ownership will be on trial. One of the greatest diseases of our national life is the spoils system in public office. Unless it can be overcome it threatens the very life of our democracy. If the public generation and distribution of power can be kept free and clean from the spoils system, there seems to me no reason why it can not be economical and effective. If government-owned power can not keep free from this incubus of political patronage, we had better discover that fact on a small scale, before we are plunged into some nation-wide scheme of public ownership.

Another object of the Tennessee Valley Authority is to make this region and the country as a whole more fully aware of the vast possibilities of electric power for enlarging the freedom and scope of modern life in the home and on the farm. This can only come with cheap power, from which all speculation and exploitation have been removed. The electric power business is one of the simpler industries of our country. It does not compare in complexity with the shoe industry, the automobile industry or the railroad industry. No vast tribute should be paid for management and financing. Brought down to its simpler necessities, electric power should be a universal convenience, supplied as city water supplies usually are, on a basis of service and not of commercial exploitation.

Lastly, the economy of electric power in the Tennessee Valley area will depend much on large-scale developments that are designed and operated as single integrated systems. The entire Tennessee River system, with its thousands of miles of streams, should be under one control and ownership, which means government ownership. An example will illustrate: all along the Tennessee River power plants can be installed with a total fall of about five hundred feet. But these are "run-of-the-river plants." That is, they provide little storage and the water must be used as it flows. At Muscle Shoals, for instance, the capacity

during high water in winter may be 600,000 kilowatts, whereas the low water of a dry summer may generate only 40,000 kilowatts. The maximum capacity at high water is fifteen times the minimum capacity at low water. Yet it is only the "prime power," or power that is nearly always available, that has much value. Now, up river on one of the main branches of the Tennessee is a power project of another sort. A high dam will produce vast storage capacity, great enough, in fact, to store a year's supply of the stream. There has been a project on foot to build a great industrial plant at this up-stream site, using the power for manufacturing purposes. The control of flow would be determined by the orders received by that one plant and by its need for power. It might be using much power, and therefore releasing much water, during the high water of winter, when there is already a superabundance of water in the river below. During the summer the plant might be shut down and water might be stored above when it is most needed below.

If the entire system should be owned and operated as one, the situaton would be very different. The entire system would be interconnected by transmission lines. During the high water of winter the upper plant would be shut down and the water stored in the reservoir. Abundant power would be available from the river plants below where no storage is available, and where the water must be used as it comes. Then, during the summer, when the river is low and electric power scarce and most valuable, the upper plant would be operated. Not only would a large amount of power be available there, if the whole year's storage were to be used in these months, but all the water used in the plant above would have to pass through each of the plants below, all the way to the mouth of the Tennessee. By such united operation probably twice as much "prime power" or dependable power could be generated for a given investment, or, in other words, the power would cost half as much per kilowatt hour.

Private utility men say that they would get the same result by trading power among themselves. That, however, does not answer the question. In the original installation of an up-river power plant, the investment which is justified in providing storage will be determined by whether an income will be produced by the water which is released from the reservoir, as it goes through other power plants down the river. For instance, the Norris Dam now being built by the government on Clinch River is made higher, and the reservoir is made larger, than would be justified by the power possibilities for the dam itself. The Norris Dam plant will be worth more as a regulator for Muscle Shoals than for the power it could generate at its own plant treated independently. The water going through Norris Dam plant will be worth twice as much at the plants below as it is at its own plant. An investment justified by the whole system would not be justified for an independent plant.

Down stream for the Norris Dam is a private power development on the Tennessee River—the Hales Bar Dam and Power Plant. The value of that private plant will be doubled by the building of Norris Dam at public expense. Only by a single organized system of water power plants for the whole Tennessee River system can the full economy be realized. With that organization, water power may cost less than half what it would if the various units should be developed independently by private companies. Water power is to have stiff competition from steam and Diesel engines. If the Tennessee River region is to realize its possibilities in water

power it can not afford to throw away this economy.

Let us take another need for social and economic planning in another field —that of county government. The county organization of this region was determined during the early days, a century or more ago, when there were few roads, and when men traveled by horseback up the creeks. The court-houses would be half a day's trip from the county borders. With modern roads and automobiles a man travels as far in half an hour as one did then in half a day. A study in some of these county court-houses discloses that in some of them all the work of the county officials can be done in one half day a week. A consolidation of counties into perhaps one sixth as many might more than cut in two the cost of local government and greatly improve its quality.

For a moment consider industry. Twice as many men are engaged in agriculture in this region as are needed to produce the crops. A balance of industry and agriculture may be very helpful. But this program has its dangers. In a large city, if a man is discharged from one job, or if his pay is reduced, he may find another. In a small, one-industry town, with the workers living on nearby farms or on small tracts, they may become virtually serfs and unable to protest against any policy of the management. A company with half a dozen plants in as many towns may close any one at its pleasure if it wishes to enforce a policy toward labor. In many of these one-industry towns only salaried managers are present, and all the profits go to far-off large cities.

Is it possible to bring about a balance of industry and agriculture and preserve the vitality of the small communities of this region, so much favored by the people, and yet prevent economic exploitation?

Such are a few of the many issues facing the Tennessee Valley Authority. There are other issues—the need for a forest policy, the possibility of developing cooperatives in selling and buying, the possibility of furnishing cooperative service to small enterprises and merchants in accounting, business management and other technical phases of work, so that the small proprietor may have approximately as good administrative advice as the large corporation.

There is the problem of vocational guidance. With a great overproduction in the standard professions, such as law, medicine, architecture, engineering and education, is it not possible to direct young men and women from these overcrowded professions to other fields where the work of the world is done badly. We might mention such new fields as the management of publicly owned utilities, the organization of groups of counties and cities for police protection, the development of planned and creative recreation facilities for small communities, the development of cooperative services for small proprietors, the development of community health services, the better feeding of unmarried working people in boarding houses. Much of the work of the world is being very badly done. Any badly done job is a call to a new or to a better calling. Can we relieve the crowding into old callings in our region by opening the way to new ones?

There are other fields of interest. The mineral resources of this region are abundant, but very often in small deposits. Is it possible to develop local mining projects, cooperatively supplied with management? There are great possibilities for developing the special skills and aptitudes of the region for the production of quality goods, as has been done in France and Vienna. America needs such an area not committed to mass production, where individuality in industry can satisfy our craving to escape monotony.

Mass production will also have its place. How to unite basic industries, so that the by-products of one become the raw material of another; how to choose locations with reference to power supply, raw materials, transportation and market, requires an integration of research seldom available to private industry. Such problems are in the picture.

But all this does not complete the idea of President Roosevelt. Increase of production and of total wealth does not necessarily mean an increase of general well-being. During recent years we have heard much about the new "economy of surplus" as though it were the first time in history that such an economy had occurred? Great surplus of men and goods is far from being new. Over and over again it has occurred. Almost our earliest recorded history is of vast economic and human surplus in Egypt. It might have been used to develop housing, sanitation, education, research and general culture. It was used to produce the most terrible servitude and some enormous piles of stone. That historic type has continued through the ages. It has not been absent from America. The past decade has not been free from it.

To escape from that use of surplus so that productive capacity shall produce well-being, that is the aim of President Roosevelt. I think a better phrase could be used to describe his purpose. He has spoken of a "new deal." That means that the cards shall be shuffled again, but that the same old process shall be repeated, with perhaps other persons holding the good hands.

What we need is not a new deal, but a new game. We need a game which, when played according to its own rules, will bring a different kind of results. The President may have been imperfect in his phrase, but he is right in his purpose. It is that the moving spirit of our social and industrial life shall be neighborliness and not the predatory impulse, that we shall guide our social and economic affairs by a realization of their total effects, to the neighbors and to the future, as well as to ourselves and to the present. Whether we are dealing with soil erosion or electric power or local government or industrial distribution, that is the goal.

How can we do that in the Tennessee Valley? The aim can be held in general, but its execution gets down to a series of particular cases—to hydraulic studies for power plants, to chemical processes of manufacture, to educational methods, to principles of sociology and of economics, to researches in government, to studies in industrial organization, production and distribution. In such an undertaking the Tennessee Valley Authority can be but a clearing house for the experience, the judgment and the insight of such men as I am addressing here to-night.

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

MEASUREMENTS OF PERSONALITY

By Dr. MARK A. MAY

PROFESSOR OF EDUCATIONAL PSYCHOLOGY, YALE UNIVERSITY

THE practical aim of all science is to predict and control the activities with which it deals. Astronomers can predict with extreme accuracy the appearance of eclipses, comets and meteors, the rise and the fall of tides and other more complicated actions of the heavenly bodies. Engineers can forecast accurately the strength of bridges, the safety of high buildings and hundreds of other practical events. In fact, the greatest achievements of modern science may be summed up in two words—prediction and control.

In the realm of human relations science has been less successful in making accurate predictions. The laws that govern human behavior are much more intricate than those that govern the stars and planets. There is in the affairs of men that so-called "personal equation" which upsets all calculations. It is easy to predict and control the behavior of mechanical men, which scientists have recently built, because the laws governing their actions are understood. Whether or not science will ever be able to predict human behavior with precision and accuracy is still an open question. Much depends on the extent to which it can be measured. There can be no accurate predictions without measurement.

Personality can not be measured by any simple yardstick, foot rule or thermometer. It has a great many different aspects and dimensions, each of which requires a different measuring instrument. Science has, therefore, not achieved a satisfactory measure of it. The greatest achievement of science to date is the invention of useful methods of measuring different aspects of personality.

I shall review these methods briefly. Suppose we have before us now our old friend John Doe. How may we discover what sort of a person John really is? Is he strong, magnetic, reliable, talented, courageous, honest and kind? Or is he weak, repulsive, cruel, cowardly, dull and deceitful? While these are only a few of the things we wish to know about him, they represent the kinds of questions we ask.

There are six different ways of finding out something about John Doe. Each represents a scientific approach to the study of his personality. First of all, we study his record. John, like every one of us, has left behind him footprints on the sands of time. These are his letters and other writings, his school grades, written applications for a gas meter or automobile license, registration for voting, and so on. His photograph will also tell you something about him, but just what it tells has not been scientifically determined. It is quite possible, and in fact easy, to find out a great deal about John Doe without ever seeing him or consulting others about him.

Second, ask those who know him. Members of his family, his teachers, his employer or his employees, his creditors, his pastor or his lawyer (if he has one), his neighbors and friends, all have very definite impressions concerning what kind of a fellow he is. Furthermore, most of them are willing to talk about him. If you approach them right, they will go so far as to rate him high, low or

average on many character and personality traits. The rating method is one of the most common devices for the scientific study of personality. Thousands of rating scales and techniques have been devised and there are now on record ratings of hundreds of thousands of individuals. But ratings are not true measures, they are at best only carefully and systematically recorded impressions and opinions. What they really measure, if anything, is John Doe's reputation, which is only one part of his personality.

Third, observe him. Three kinds of observations will be useful. First, note his physical appearance, second, his expressive movements, and third, his actual conduct. If John Doe is a little fellow, far below the average in size, it is likely that he has developed personality traits which compensate for his physique. If, on the other hand, he is a big fellow, his personality will probably be quite different. The German scientist, Kretschmer, has studied the physical build of many insane persons and finds a close parallel between body types and types of insanity. Many attempts have been made to relate facial features to personality. But these measures have not been scientifically verified.

More significant are the expressive movements. John Doe expresses his true personality in the manner and form of his actions. He has a certain gait which is all his own. The same is true of his handwriting, his style of language, manner of dress, his gestures and other movements which are more or less unconscious and involuntary. Thus each of us has his own peculiar style and form which betray his inner self to the trained eye of the scientific observer. Hans Gross, the German criminologist, developed the theory that every criminal has his own individual style or form of committing a crime, and always leaves behind him certain clues by which he can be identified.

The quality of the human voice also expresses personality. An English psychologist, Professor T. H. Pear, conducted an interesting experiment on what he called the radio-personality. He arranged for nine mystery speakers to broadcast the same speech. The radio audience attempted to guess the age, sex, occupation, locality of birth and other characteristics of each speaker. The results were surprisingly accurate, indicating that the quality of the speaker's voice betrays, in some degree at least, not only his sex, age and occupation but many other personality traits. One of the speakers was a detective-sergeant who was frequently described as "a robust man of heavy build, stout and burly."

Going back to our friend John Doe, one of the best ways of finding out what kind of a person he is is to observe his conduct. How does he behave at home with his family or when the family is not around? How does he behave on the street, in his office, at social gatherings and in other walks of life? To really understand him, we must observe not only the manner in which he does these things, but what he actually accomplishes. What he does makes him what he is. But it is very difficult to record scientifically observations of human conduct. It looks easy, but try it and you will find that you can not observe and record one tenth, no not one one hundredth, of all the things John Doe does, unless you do it in a very general way. Science is just beginning to find how to make accurate observations of human behavior. It is also difficult to determine which of John Doe's actions are worth recording. Some of his acts are more significant than others. Some psychoanalysts have suggested that one significant set of acts are slips of the tongue, pen or fingers. These slips are involuntary movements which are supposed to be especially symptomatic of the true personality.

The fourth way of studying John Doe's personality is to interview him. If you can establish friendly relations with him either as a scientist in quest of knowledge or as his physician, lawyer or pastor, he will submit to direct questioning and will tell you a great many things about himself. Your task is to select the questions that will bring out the aspects of his personality in which you are for the moment interested. But if he will not submit to direct questioning you will have to employ methods that are more subtle and indirect. The usual procedure is to get him talking about anything at all, and, if he is like most persons, he will eventually get around to telling you about himself. The interview is the method most commonly used by employers in sizing up the personalities of prospective employees; it is also the method used by psychiatrists in diagnosing the personalities of the insane and the mentally maladjusted.

The fifth method is psychological tests. Psychological tests represent the most significant efforts to measure personality. A test is essentially a measuring device. There are a great many different kinds of tests, each intended to measure a different phase or aspect of personality. The best are known as intelligence tests. There are also tests of special abilities, talents and aptitudes. There are tests of instincts and emotions, of social adjustments, of educational achievement, of moral knowledge and conduct, including such types of conduct as honesty, cooperation, generosity, courage, will-power, self-control and the like. There are also tests of appreciation of art, music and literature, tests of likes and dislikes; tests of social attitudes, opinions and beliefs; tests of interests in occupations, games and sports. All these are efforts to measure various aspects of the personality.

There is in addition a special kind of a test known as a general personality test. This test, which exists in various forms, is really a questionnaire which inquires into symptoms of personal adjustment or maladjustment. It is a sampler of symptoms. Some of the questions are: Do you day dream frequently? Do you blush very often? Are your feelings easily hurt? Do you make new friends easily? Do you haggle over prices with salesmen? Do you hesitate to borrow things from your neighbor? The theory is that while no single question taken by itself is significant, yet a large number of them reveal characteristic modes of adjustment which are symptomatic of normal or abnormal personality.

The sixth and final method of studying personality is by experiment. Since the laboratory is the workshop of the scientist, personality must eventually come under instruments of precise measurement. To secure scientific data on John Doe he must submit to experimentation. But there is a popular prejudice against experimenting on human beings. Such prejudices are usually based on detective stories and movies and are quite without foundation in fact. Most psychological experiments are 100 per cent. harmless, most of them are interesting to the subject and some of them are good fun. Laboratories are now equipped with instruments for measuring not only the physical characteristics of human subjects but also their mental and physical functions as well. Many of these functions, if not all, are definitely related to personality. For example, the fluids of the body, including the blood, the saliva, the urine, the spinal fluids, and others, are so chemically constituted that changes in their compositions are frequently accompanied by changes in behavior. In fact, some scientists hold that in the electrical and chemical phenomena of the body lies the solution to the problem of the prediction and control of conduct.

All these efforts to study, estimate and measure the human personality have

practical advantages. Two of the greatest social problems now confronting civilization are crime and insanity, both of which are in the final analysis problems of personality. There are also the problems of divorce, of graft, of racketeering, of suicide, and many others which depend for their final solution on an understanding of human nature.

We are all speculating in "futures," whether we are buying distillery stocks or German marks or wheat and cotton. The future is a speculation because of the uncertainty of the "personal equation" in all human affairs. It is this unpredictable human element that causes runs on banks, stock market crashes, labor strikes, frozen credits, and disturbs the whole economic order. There is no doubt that during the depression the psychological factor has played an important part. It is the hope of science that this human element may be analyzed, understood and measured—and finally predicted and controlled.

POETRY OF THE ROCKS

By Dr. R. S. BASSLER

CURATOR OF GEOLOGY, U. S. NATIONAL MUSEUM

MAN'S natural curiosity about his earthly habitation has ever made earth science, geology, the science of the rocks, a subject of keen interest to him. What has happened on the earth down through the ages and what has life, especially man, had to do with it? These are questions which thinkers as far back as Pythagoras and Aristotle have tried to answer.

Geology has grown to be perhaps the most comprehensive of the sciences, for it deals with the story of the earth and its inhabitants from the time our planet was a fiery mass revolving in its charted course through the heavens and subject only to physical laws, down to the present when life has become such a predominant factor. If one has a limited amount of time to obtain a general knowledge of science, geology will surely give a more comprehensive view than one of the more specialized branches.

That there is no royal road to learning and that only persistent, painstaking effort will lead to the acquisition of knowledge has been pointed out time and again. However, education has long sought for a more vital approach to learning than the memory method. Pictures, both moving and still, are now widely employed in the teaching of science, for it is recognized that we learn more readily by looking at things than by memorizing facts about them.

The principle holds still better if the object itself can be viewed. In geology the visual method of learning is especially applicable because every mountainside or stream valley reveals chapters of earth history often quite puzzling to the layman but usually plainly visible to the student of nature.

Still another method of impressing the facts of science is through the emotions, particularly through the appreciation of literature or music. Long ago Herbert Spencer pointed out in his "Essays" that not only does science underlie sculpture, painting, music and poetry, but that science itself is poetic. He further has written that science opens up realms of poetry where to the unscientific all is blank, and he quotes Hugh Miller's books on geology as scientific works inciting poetry.

Much of the poetry of nature which has endured has been written by students who have described their impressions with such care that they are scien-

tifically correct, even though the underlying principles may not have been understood. The geologist is seldom a poet and the poet rarely has an appreciation of geology, yet often they evidence a mutual understanding. Byron expresses the feelings of the appreciative geologist when he writes:

To sit on rocks—to muse o'er flood and fell—
To slowly trace the forest's shady scene,
Where things that own not Man's dominion dwell,
And mortal foot hath ne'er or rarely been;
To climb the trackless mountain all unseen,
With the wild flock that never needs a fold;
Alone o'er steeps and foaming falls to lean;
This is not Solitude—'tis but to hold
Converse with Nature's charms, and view her stores unrolled.

The first chapter of Genesis, that great poem from the pen of the inspired philosophers, is an abridged volume of geologic history. Its seven days or eons of time so closely parallel the great eras of earth history as determined from the evidence of the rocks that the old-time idea of the conflict between religion and science based on an erroneous conception of the Biblical account should be discarded once for all.

Students of geology can recognize in this account the story of evolution which parallels that presented in the rocks, namely the change of the earth itself from the first great void to the present arrangement of land and sea, then the upward progression of life from the first most primitive plants to the simplest marine animals, and on to the more complicated land vertebrates, finally culminating in man.

The story of evolution is succinctly outlined in the introductory stanza of Carruth's "Each in His Own Tongue," a poem in which the relation of the Creator to the beautiful things of life is feelingly portrayed.

A Fire-Mist and a planet—
A crystal and a cell—
A jelly-fish and a saurian,
And caves where the cave-men dwell;
Then a sense of law and beauty,
And a face turned from the clod—
Some call it Evolution,
And others call it God.

In both the Biblical and scientific accounts of the earth's origin, it is evident that eons of time had elapsed before man appeared upon its surface. During this long interval physical processes in the form of wind, water and temperature were actively at work in some places slowly leveling mountains, in others cutting valleys only to be later filled with sediments, and in other ways modifying the face of the earth in preparation, as we sometimes boastfully say, for man's coming.

All of these processes are described under the general term of weathering, but perhaps the most far-reaching of them is the wind. A logical discussion of this phase of earth history, termed "physical geology," will start with the work of the wind and continue with that of the rain, which, sinking into the earth, forms the ground water, or running off the surface as streams finally enters its original source, the ocean. In this talk only the physical elements and their work concerned in geologic history will be discussed.

The geologic effect of the winds is both constructive and destructive. They control weather conditions, particularly rainfall, which in turn through the streams and by solution, weathers away or breaks down the land surface. Winds also create ocean waves and currents in the sea and thus increase their geologic significance both by wearing away the rocks at one place and by depositing the eroded material elsewhere.

The beneficent west wind, wafting the warm, moisture-bearing clouds to the British Isles and making life pleasurable there, in a latitude as far north as our own Labrador, forms the subject of Lord Tennyson's song of "Sweet and Low" from "The Princess."

Sweet and low, sweet and low,
  Wind of the western sea,
Low, low, breathe and blow,
  Wind of the western sea!
Over the rolling waters go,
Come from the dying moon, and blow,
  Blow him again to me:
While my little one, while my pretty one, sleeps.

On the other hand, the work of the wind and the destructive forces set free by its action are dramatically portrayed by Austin Dobson in his "Song of the Sea Wind." Here he graphically describes its cutting force on the land, then its erosive power along the shore line and its explosive ability from air compressed in the sea caves and finally, in the closing stanza, its subsidence and reckoning:

How it sings, sings, sings,
  Blowing sharply from the sea-line,
With an edge of salt that stings;
  How it laughs aloud, and passes
  As it cuts the close cliff-grasses;
    How it sings again, and whistles
    As it shakes the stout sea-thistles—
      How it sings!

How it roars, roars, roars,
  In the iron under-caverns,
In the hollows of the shores;
  How it roars anew, and thunders,
As the strong hull splits and sunders:
  And the spent ship, tempest driven,
  On the reef lies rent and riven—
        How it roars!

How it wails, wails, wails,
  In the tangle of the wreckage,
In the flapping of the sails;
  How it sobs away, subsiding,
Like a tired child, after chiding;
  And across the ground-swell rolling,
You can hear the bell-buoy tolling—
  How it wails!

In his poem, "Winter," Robert Burns expresses his appreciation of the raw snowy days with their fierce blasts and he seems to derive real pleasure from a comparison of his own sad fate with them. Others of his poems indicate how he was influenced by the geologic background of his home in the Scottish Highlands where the prevailing hard granites and other igneous rocks weather into a countryside with an equally harsh environment.

The wintry west extends his blast,
  And hail and rain does blaw;
Or the stormy north sends driven forth
  The blinding sleet and snaw:
Wild-tumbling brown, the burn come down,
  And roars frae bank to brae:
While bird and beast in covert rest,
  And pass the heartless day.

Weather conditions brought about by the winds often result in rain which, absorbed upon reaching the earth, becomes ground water. Besides supplying the water for human activities and furnishing moisture for plants, ground water in limestone regions works insidiously under the surface, dissolving away the rocks, forming caves and otherwise eroding the land. Rain and ground water were poetically appreciated long ago in the poem called "Drinking" by the great lyric poet. Anacreon, who concludes his lines with a question still quite timely:

The thirsty earth soaks up the rain,
And drinks, and gapes for drink again,
The plants suck in the earth, and are
With constant drinking fresh and fair,
The sea itself—which one would think
Should have but little need of drink—
Drinks ten thousand rivers up,
So filled that they o'erflow the cup.
The busy sun—and one would guess
By's drunken fiery face no less—
Drinks up the sea, and when he's done,
The moon and stars drink up the sun:
They drink and dance by their own light;
They drink and revel all the night.
Nothing in nature's sober found,
But an eternal health goes round.
Fill up the bowl then, fill it high,
Fill up the glasses there; for why
Should every creature drink but I;
Why, man of morals, tell me why?

Streams are very lifelike in their actions. They go through the various phases of life, youth, maturity and old age and often exhibit real human emotions. A youthful stream with few or no tributaries will courageously attack the

land of its birth. Its life work, the task of breaking down the rocks in its course, is before it. Upon reaching maturity, it is found to have divided into many branches and to have cut the former land surface into a series of hills and valleys. When old age arrives, even the hills have been eroded away and the stream, tired from its exertions, no longer supports a family of tributaries, but now meanders sluggishly over the low plain it has formed from the highland of its youth. The Colorado, in the Grand Canyon, is a vigorous youngster, but Tennyson's "Brook" is a baby stream with all its childish ways.

I chatter over stony ways
In little sharps and trebles;
I bubble into eddying bays,
I babble on the pebbles.

"As old as the hills" is an oft-repeated simile, but it should read "as old as the streams," for they precede the hills and cause their formation. In maturity, stream erosion is taking its full toll of the hills, or as the poet describes it:

The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands
Like clouds they shape themselves and go.

In old age the wear and tear of the stream's life is at an end and peace and rest are at hand. Robert Burns' "Sweet Afton" is such a stream:

Flow gently, sweet Afton, among thy green braes,
Flow gently, I'll sing thee a song in thy praise;
My Mary's asleep by thy murmuring stream,
Flow gently, sweet Afton, disturb not her dream.

The ocean, the ultimate destination of old-age streams as well as all other watercourses, is their birthplace and final resting place. Covering three-quarters of the globe, the ocean serves as the great stabilizer of climate. The sun's unfailing energy has, of course, caused the remarkable constancy of the earth's climate these hundreds of millions of years, but the ocean, by storing up excess warmth and distributing it through currents into the higher latitudes, has played a large part in equalizing temperature.

The more obvious effects of the ocean are seen in the gnawing action of the waves along certain sections of the seashores and in the depositing at other places of the eroded material as sandbars and other well-known near-shore features. The theme of the waves breaking on a rocky shore is used by Tennyson in his well-known poem, "Break, Break, Break":

Break, break, break,
On thy cold grey stones, O sea!
And I would that my tongue could utter
The thoughts that arise in me.

Probably the most feeling poem touching upon the phenomena of the sea is Tennyson's "Crossing the Bar," written in the latter part of his life, a poem which may very well conclude this discussion of poetry in rocks.

Sunset and evening star,
And one clear call for me!
And may there be no moaning of the bar,
When I put out to sea,
But such a tide as moving seems asleep,
Too full for sound and foam,
When that which draw from out the boundless deep
Turns again home.
Twilight and evening bell,
And after that the dark!
And may there be no sadness of farewell,
When I embark;

For tho' from out our bourne of Time and Place
The flood may bear me far,
I hope to see my Pilot face to face
When I have crost the bar.

EXPLORING FOR PLANTS IN THE SOUTHEASTERN STATES

By Dr. EDGAR T. WHERRY

ASSOCIATE PROFESSOR OF BOTANY, UNIVERSITY OF PENNSYLVANIA

ONE of the most pressing tasks of the plant geographer is to ascertain as fully as practicable the present distribution of the various kinds of plants over the surface of the earth, before civilized man succeeds in destroying all natural habitats and exterminating their occupants. While many manuals and floras give in a general way the ranges of such species as occur within the areas covered, accurate distributional data are at hand for very few. The lack of such information is especially serious in the case of plants endemic to the southeastern United States, where there has been so little collecting that the range of even conspicuous objects like the pitcher-plants is but imperfectly reflected by specimens in herbaria. I was accordingly especially glad to be invited by Mr. Louis Burk, the well-known Philadelphia horticulturist, to obtain for him a complete collection of the species and varieties of *Sarracenia*, in the summer of 1932. Not only would such a trip make it possible to fill in many gaps in the recorded ranges of these plants, but also there would be a chance to study in the field undescribed ones as to which more or less unsatisfactory data were at hand.

Late in June I drove to Washington, D. C., and was fortunate in having Mr. James E. Benedict, Jr., join me for the trip. Continuing southward on U. S. Route 1, our first stopping point was Raleigh, North Carolina, where we called on Professor Bertram W. Wells. He not only furnished us information as to pitcher-plant localities in the southern part of that state, but also showed us a tiny meadow not far from the city where by good fortune a few pitcher-plants still survived the encroachments of agriculture. Two species were represented, the wide-spread yellow pitcher-plant (*S. flava*) and a relative of the side-saddle pitcher-plant (*S. purpurea*), which we especially wished to study. In his "Autikon Botanikon," published in 1840, Rafinesque had pointed out what he considered specific differences between the northern and southern representatives of this species, and had named the southern one *S. venosa;* but his work has been ignored by all subsequent students of these plants. At this locality its aspect was certainly quite unlike that of the familiar pitcher-plant of New England and the Great Lakes region, and we felt disposed to accept Rafinesque's interpretation of it; but other occurrences seen in the course of the trip indicated the two to intergrade too much to be maintained as independent species. Additional data as to pitcher-plant localities were obtained from Professor William C. Coker at Chapel Hill, and we set out for central Georgia. At Macon we were joined by Dr. Charles C. Harrold for a two-day trip on the coastal plain of the state.

As we traveled southeast, pitcher-plants began to appear in the swamps in the vicinity of Swainsboro; these comprised not only the tall and conspicuous *Sarracenia flava*, but also the diminutive hooded (*S. minor*) and parrot pitcher-plant (*S. psittacina*). Michaux had reported the latter from "Augusta, Georgia, to Florida," and, desiring to obtain roots from as far north as possible, we kept searching for it in one county after another, but the most northern colony to

be found lay 10 miles south of Millen and thus fully 50 miles south of Augusta. Several rooted clumps were collected, packed in wet moss, carried with us until we could find a state inspector and get them certified as pest-free, and then shipped home. Some of these were planted outdoors in a wild-life preserve controlled by Mr. Burk in southern New Jersey, where they have survived the first winter, at least. The remainder were held in a cool greenhouse, and bloomed freely during early spring.

Pitcher-plants were, however, not the only thing to claim our attention in this part of the country. We planned to make an effort to rescue a native tree which is on the verge of extinction. This plant, discovered by Stephen Elliott in the early 1800's and named in his honor *Elliottia* by Muhlenberg, is a primitive member of the heath family. The genus is monotypic, being represented by the single species *E. racemosa*, and its nearest relative is the genus *Tripetaleia* of Japan. These are evidently relics of the late Cretaceous and early Tertiary floras which spread widely over northern lands, but have been restricted by subsequent geological events, especially the Pleistocene glaciation, to remote isolated areas.

Elliottia is a small tree, attaining a height of about 15 feet and a trunk diameter of 2 or 3 inches. It spreads by rootstocks into colonies of a score or two of individuals, and about the end of June produces attractive large panicles of small white delicately scented flowers. These attract various sorts of bees, which carry pollen from flower to flower; as a rule, however, no fertilization occurs, and the ovaries soon drop from the pedicels. Evidently individual plants are sterile to their own pollen, and as each of the 5 or 6 known colonies is apparently the result of vegetative propagation from a single seedling, this sterility extends throughout. Before the coming of the white man colonies must have grown close enough together for pollen to be borne by insects from one to another, and seed was sometimes produced. Clearing the land for agriculture and burning over the woods destroyed so many, however, that this no longer occurs, and the seed of the species is actually unknown to science.

FIG. 1. OUR SHOWIEST SPECIES OF PITCHER-PLANT IS *S. DRUMMONDII* WITH THE UPPER PART OF THE LEAVES WHITE, VEINED WITH GREEN AND RED. THIS VIEW WAS TAKEN AT ITS NORTHERNMOST KNOWN STATION, NEAR AMERICUS, GEORGIA.

The current practise in that region of burning the low-growing vegetation every year or two causes the *Elliottia*, like many other plants which, when undisturbed, have an arborescent habit, to send up numerous small shoots from their woody underground parts, and thus produce shrubby thickets. These often become so dense that reproduction of the longleaf pine and other valuable trees is prevented, until another fire destroys the brush to which the preceding one gave rise, which has led to the curious idea held in many circles that frequent burning is natural and desirable. No doubt the great pine forests of the coastal plain got started in the first place when particularly severe fires destroyed whatever deciduous climax forest formerly occupied the areas; but the infrequency of charred rings in stumps and of charcoal layers in peat deposits shows that before the white man came fires occurred only at intervals of many years. Unless and until the present frequency of fires shall be reduced to that of primeval times by protective measures and by education, all but the most vigorous and aggressive of the native plants of that region are doomed to extinction in the near future, and it seems idle to talk about "reforesting the south."

Because, then, of the impending disappearance from native habitats of this relic of past geologic times, *Elliottia*, all possible efforts to get it into cultivation are worth while. With this in view, Mr. Harry W. Trudell and I had twice before visited this region and had located certain of the remaining colonies of the tree, in part through directions kindly furnished by Dr. Roland M. Harper (who, I should state at this point, disagrees with me completely as to the fire situation). Both times we had found but a single colony in bloom, the others having been seriously damaged by the fires of those years. On the present trip, however, conditions were more favorable; not only were two previously known colonies blooming, but Dr. Wallace Kennedy, of Metter, had discovered near there a new one, which had escaped burning for a number of years and approached the normal arborescent habit of the species.

Pollen was accordingly carried, by what I can not refrain from terming an "automobee," from one locality, which may be designated A, some 5 miles to locality B, and from the latter 75 miles to locality C. The pollinated plants were carefully located by landmarks, and Dr. Harrold planned to return in the fall to see if any seed had matured. He was unfortunately prevented from doing so by serious illness, so what occurred at locality C is indeterminate. During the winter Dr. Kennedy went out to locality B, and found that capsules had actually formed on the pollinated plants, but by that time dehiscence had occurred, and the contents had fallen out, so the seed of the species is still unknown to science. Horticulturists have now become interested, however, and clumps from different colonies have been planted side by side on the grounds of Dr. Lee, in Macon, and of Professor De Loach, in Statesboro, where fire can be kept out and the plants watched closely, so by another year we should know what the seed is like, and have some from which seedlings can be grown for cultivation elsewhere.

Another group of plants on which data as to geographic range were being sought on this trip was the phloxes. Many of the counties of Georgia traversed yielded one which, though exceedingly variable in habit and leaf-shape, could only be classed as *P. glaberrima* L. In an alder thicket near La Grange, Troup County, we found a colony of the tallest plants of this species on record, attaining a height of 175 cm. Driving south through Webster County and watching the roadsides for plants of interest, we suddenly caught a flash of purple on a plant which looked different

FIG. 2. ONE OF THE FEW *SARRACENIA* MEADOWS STILL PRESERVED NEAR THEODORE, ALABAMA. THE SPECIES ARE *S. drummondii* AND *S. sledgei*, WITH INNUMERABLE HYBRIDS BETWEEN THEM, SHOWING ALL SORTS OF COMBINATIONS OF CHARACTERS.

from any previously seen. On investigation this proved to be *Phlox floridana*, which had not been previously reported north of Thomas County, so that our find extended its known range by more than 100 miles. Other new stations for this species in Georgia and Alabama were also found later.

Showiest of all the species of *Sarracenia* is the white-top pitcher-plant, usually known technically as *S. drummondii*, although Rafinesque's name *S. leucophylla* has many years' priority. Amateur botanists have reported it to grow as far up as North Carolina, but the northernmost locality represented by specimens in herbaria is Americus, Georgia. After an hour's search in that vicinity we found in a swamp a small colony which, by a fortunate chance, had not been destroyed by cultivation. Here the stock of the species for Mr. Burk's collection was obtained, and although it is still too early to tell whether the clump planted outdoors in southern New Jersey will survive, those wintered over in the cool greenhouse have grown and bloomed well. (See Fig. 1.)

Another member of the genus does not grow east of Mobile, Alabama, so we traveled slowly toward that place, collecting various plants of interest along the way. The technical name of the species in question is *S. sledgei* Macfarlane, and, as its flowers are lighter in color than those of any other species, it seems most aptly termed the pale pitcher-plant. This proved to occur in a number of swamps, and we soon had some plants ready to send off. Here we were so fortunate as to meet Mr. T. S. Van Aller, who not only inspected our plants and certified them as safe for shipment, but also guided us to several pitcher-plant meadows which we would not have found otherwise. In most of

the localities draining, burning and other destructive activities of civilized man have greatly reduced the numbers of these plants, but one locality near Theodore proved to be still undisturbed. (See Fig. 2.) Here countless thousands of *S. sledgei* and *S. drummondii* grew together, along with a host of hybrids showing every conceivable gradation between and combination of the characters of the two parents. It seems a pity that there is no one in the region sufficiently interested in conservation to buy up this bit of meadow and save it for investigation by geneticists and enjoyment by nature lovers of the future.

In April, 1910, while carrying on his fascinating studies of the relations between insects and pitcher-plants, Dr. Frank Morton Jones had spent some time at Theodore, and had observed in one near-by meadow a pink-flowered form of *S. venosa*. He had furnished us approximate directions as to its location, and we soon found what appeared to be the right spot. In July, of course, pitcher-plant petals are withered, but we dug a few plants and shipped them to Philadelphia in the hope that they might bloom in the greenhouse the following spring. This hope has now been realized; and it turned out that we had struck the right spot. The parts of the flower which in most pitcher-plants are green or bronzy—the bracts, sepals and style-umbrella—are in this one nearly white, while the petals have a lovely rose color, unlike that of any other *Sarracenia*.

Few herbarium records existing for Mississippi plants, we visited bogs in two of the eastern counties of that state, obtaining specimens of several Sarracenias and phloxes. Next we went to Havana, Alabama, and found the famous colony of the hybrid spleenwort (*Asplenium ebenoides*)—the only one in which fertility has been attained—to be in good condition. We then called on Dr. Roland M. Harper at Tuscaloosa, and obtained from him directions as to certain *Sarracenia* localities in the northern part of this state. Along the Sipsey River we found a colony of the Allegheny filmy-fern (*Trichomanes boscianum*), but search for its diminutive relative, *T. petersii*, was unsuccessful.

In Chilton County we located a colony of a red-flowered pitcher-plant, but it was not in good enough condition to establish its identity. We then set out for the valley of the Little River east of Fort Payne, where a yellow-flowered one was reported. In spite of many hours' search in every conceivable type of habitat, we were unsuccessful in finding it there, but Dr. Harper had fortunately observed it, also, near Center. On reaching that place we found that, although recent clearing of the land for agriculture and burning over of the swamps, even where no such use was practicable, had nearly exterminated it, a few small clumps had somehow managed to escape destruction. Both in the field and in the greenhouse, where it bloomed the following spring, this plant showed a number of differences from its nearest relative, *S. flava*, and is to be classed as an independent species.

The mountains of North Carolina were our next objective, for there grows the red-flowered pitcher-plant known as *Sarracenia jonesii*, the distinctness of which had only been recognized in 1929. Its colonies proved to have been nearly destroyed by drainage of the swamps and by the raids of vandals from the towns, but enough remained to enable this species to be added to the collection. With it grew some beautifully veined *Sarracenia venosa*. Ordinarily, when two closely related species or varieties exist, the more southern one tends to grow in the coastal plain, the more northern in the mountains; in this case, however, the southern representative grows both at low and high elevations. We also found hybrids between *S. venosa* and *S. jonesii* as yet undescribed.

Never having had an opportunity to make habitat photographs of and color notes on the rather rare *Phlox amplifolia* Britton, we then made an effort to find this plant in several counties where it had been reported. The roadsides were gay with another member of the genus—*P. carolina* L., long mistaken for various other species—but for some time we were unable to find a single colony of the one especially sought. Finally, however, it turned up in thickets in the vicinity of Willets, Jackson County, and the desired data upon it were obtained.

Leaving the mountains, we next drove to Charleston, South Carolina, where some of the specimens in the Elliott Herbarium, preserved at the Charleston Museum, were studied, and then made for Summerville. How abundant pitcher-plants formerly were here is well shown by the splendid photograph in Macfarlane's Monograph on the family in Engler's "Pflanzenreich"; but when we reached the spot where this had been taken, a very different sight met our eyes. Drainage of the swamps and burning of the woods had destroyed practically everything, and it was only after considerable search that we found even a single pitcher-plant in the midst of the rank, weedy grass and brush that had come in.

Three species of pitcher-plants remained to be collected at the northernmost margin of their range, so that they would be as hardy as possible. Eastern South Carolina proved, however, to be poor collecting ground, for droughts extending over a period of years had so lowered the water-table that many former swamps were now dry land. Moreover, the local farmers had taken to planting crops in the lower areas, and many a time when we pushed through pine woods toward what should have been a *Sarracenia* bog we found only a *Zea Mays* or *Gossypium* bog instead. *Sarracenia minor* was finally obtained in the neighborhood of Florence, South Carolina, and we then made for Lake Waccamaw, North Carolina. A few months before, Mr. Benedict had discovered here a northern outpost of the Florida swamp-fern, *Dryopteris floridana*, and of this we were able to obtain a good series of pressed specimens.

The sweet pitcher-plant, *S. rubra*, eluded us for some time, but we finally located it in wet woods on the outskirts of Fayetteville, and roots were duly collected. Before leaving this part of the country, an attempt was made to obtain some of the remarkable little insectivorous plant, *Dionaea muscipula*, from a northern marginal occurrence, but the drought proved to have destroyed practically all of it, and only a very small clump could be obtained for planting out in the New Jersey preserve. Here it has survived the first winter, however, so there is some hope that it may become established there. The last pitcher-plant, *S. flava*, was obtained near New Bohemia, Prince Charles County, Virginia, and the series was complete.

DR. WERNER HEISENBERG

THE PROGRESS OF SCIENCE

AWARD OF THE NOBEL PRIZES IN PHYSICS TO PROFESSORS HEISENBERG, SCHROEDINGER AND DIRAC

THE 1932 and 1933 Nobel prizes have been granted to three leaders in theoretical physics. Werner Heisenberg, of Leipzig, was awarded the 1932 prize for his development of quantum mechanics leading to the discovery of the allotropic forms of hydrogen; the 1933 prize is divided between Erwin Schroedinger, of Berlin, now at Oxford, and P. A. M. Dirac, of Cambridge, England, for the new form they have given to the quantum theory of the atom. By this award the high estimation and the great importance of purely theoretical work for the development of modern physics is emphasized by the Nobel Committee, which is known usually to lay special stress rather upon the experimental side.

Since the beginning of this century atomic physics has won more and more importance. The nuclear model developed just before the war by Rutherford and Bohr created a very suggestive picture of the atom leading to innumerable experimental discoveries, especially in spectroscopy and the study of the reactions between atoms and electrons. The idea of the heavy, positively charged nucleus, surrounded by negatively charged light electrons rotating like the planets around the sun, appealed to the imagination of scientists, and attracted the interest and collaboration of most physicists. But after the very intensive work of about ten years it became more and more obvious—as was early predicted by Niels Bohr—that this theory was only a preliminary step in the study of the atom and that the laws of classical mechanics had to be changed when dealing with the minute dimensions of the atom, a world ruled by Planck's constant h of elementary action. This change came from three different sides nearly simultaneously, and these three different modes of the new mechanics have now been crowned by the highest scientific honor.

Indeed, the new mechanics gives an entirely consistent theory of all atomic and molecular phenomena outside the nucleus, as long as the velocities involved are not comparable with the velocity of light; and its results have with this restriction so far never been found to be in contradiction with the experiments. The field thus covered includes all of spectroscopy, the collision phenomena between molecules and electrons and the mystery of chemical forces. There are even attempts to understand processes of radioactivity taking place inside the nucleus. The consequent expansion of the theory led after many struggles rather to a statistical than to a causal conception of nature. It modified thus our previous convictions concerning nature and almost crossed the borders of pure science reaching into the field of metaphysics.

Professor Heisenberg, who is now 32 years old, studied with Arnold Sommerfeld in Munich, with Max Born in Goettingen and with Niels Bohr in Copenhagen. He won his first reputation at the age of 21, when he introduced half quantum numbers for treating the natural multiplicity of spectral lines and their Zeeman effect, *i.e.*, their splitting in a magnetic field into groups of polarized lines. The idea of half quantum numbers was so original and new that it

DR. ERWIN SCHROEDINGER

created a real sensation when its youthful author defended it in a modest but very convincing way at a scientific congress in Goettingen against a whole group of colleagues, headed by Niels Bohr. It is worth mentioning that these half quantum numbers reappear in his quantum mechanics.

The idea of Heisenberg's mechanics was born in Copenhagen in the stimulating circle around his beloved teacher Bohr, but it was published and worked out in Goettingen in collaboration with Max Born and Pascual Jordan. Heisenberg's aim was to discard the unobservable "orbits" of electrons, which played a predominant rôle in the previous theory, and to deal only with properties like frequency and intensity of spectral lines which can be observed. This method was recognized by Born as being in close connection with the well-known matrix symbolism of mathematics. It was worked out by Born, Heisenberg and Jordan within a few months to a consistent theory of spectroscopy, including an attempt to quantize the electromagnetic field.

One of the great successes of the new mechanics was Heisenberg's treatment of the problem of two and more electrons and his discovery of the "resonance coupling" between identical electrons. This discovery gives an explanation for the splitting of the helium spectrum into two—the para- and the ortho-helium spectrum. The application of this result to the hydrogen molecule, where the two identical nuclei play the rôle of the two electrons of the helium atom, led D. M. Dennison in Ann Arbor to the prediction of two allotropic forms of hydrogen, the para- and the ortho-hydrogen. His surprising prediction was later experimentally verified by K. F. Bonhoeffer and P. Harteck in the "Kaiser Wilhelm Institut für physikalische Chemie und Electrochemie" in Berlin-Dahlem, and by Eucken and Hiller in Breslau.

From a more general point of view, Heisenberg's greatest achievement was the recognition of the impossibility of the simultaneous accurate determination of the speed and the position of an electron, generalized in the famous uncertainty principle. He was led to this discovery by the realization of the statistical meaning of the fundamental quantities of the new mechanics.

Shortly after Heisenberg, but without connection with his theory, Schroedinger started from the conception of de Broglie, that the motion of particles may be represented by progressive waves. By generalizing this idea he arrived at a differential equation for the wave motion which corresponds to the motion of particles in space in a manner analogous to that in which the change of the electromagnetic field described by Maxwell's differential equations corresponds to the motion of light quanta. The conception of waves representing particles was very much strengthened by the fundamental discovery of Davisson and Germer, who showed experimentally that moving electrons can produce interference patterns, very similar to those of light waves.

Schroedinger's differential equation gives the clue for the understanding of the quantized states of atoms and molecules which, up to that time, defied the treatment by continuous functions. In virtue of the possibility of applying well-known mathematical methods to his equation, Schroedinger opened a broad road to the solution of atomic problems, and in a series of brilliant papers he traveled a long way along this road. Many questions indeed, such as the problem of resonance coupling and of the hydrogen molecule, scarcely could have

DR. PAUL ADRIEN MAURICE DIRAC

been solved without his powerful equation.

The explanation of the sharp energy states of atoms given by Schroedinger's wave mechanics is just as simple and "anschaulich" as the explanation of the well-defined tunes of a bell, given by the differential equations of classical mechanics. In Heisenberg's quantum mechanics the discrete energy states were much more explicity postulated. And yet, the physical contents of both theories have been shown by Schroedinger to be identical—in spite of their totally different aspects.

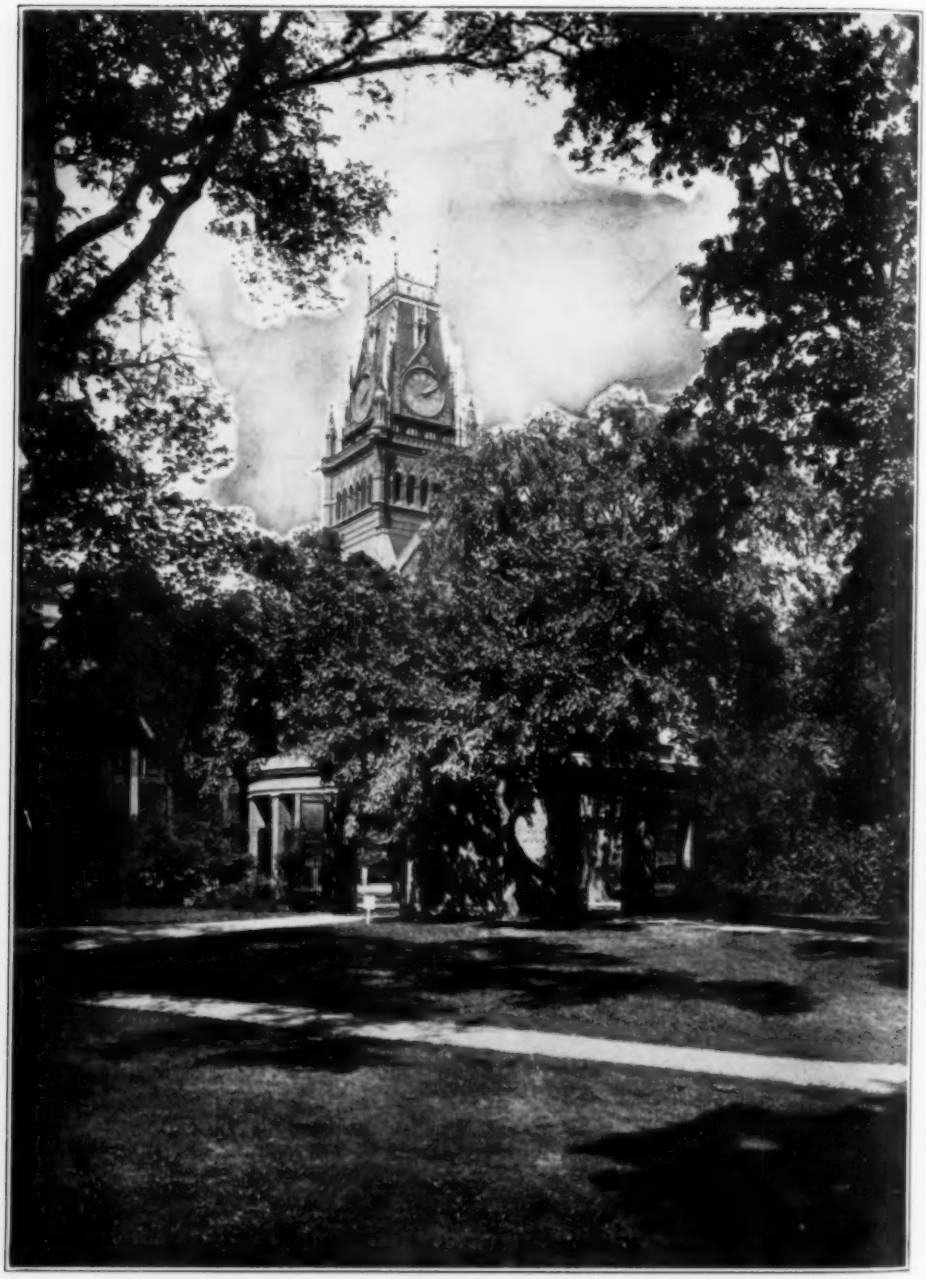
The third scientist awarded the Nobel prize is P. A. M. Dirac. After the stimulation received from the work of Heisenberg, he built up almost the whole system of quantum mechanics, independently of all other investigators, using his own mathematical calculus, the "q-numbers." The step-by-step development of this theory may still be considered as his greatest achievement. Not only the consistency in every one of his works has to be admired, but still more their organic entity. The culmination of this series of articles is his famous light-theory, which for the first time connects the radiation process itself intrinsically with the mechanics of the atom. His papers contain—apart from some more or less special applications—almost all the results of the non-relativistic quantum theories which are nowadays the common property of theoretical physicists.

The mathematical tool, the q-number algebra, developed by Dirac in these works, makes the reading of his papers more difficult; and his methods have often been the target of attacks because of lack of mathematical rigor. Nothing manifests more strongly the fertility of his ideas than the fact that it hardly is possible nowadays to find a theoretical physicist unfamiliar with q-numbers, nor any critic of the rigor of his δ-function method who would not use it himself—even though exhibiting his results with the more accepted methods to the public.

The problems of relativistic quantum mechanics reveal another side of Dirac's abilities. The stepwise penetration of the subject does not seem to be possible here any more, and his mind is forced to greater jumps. We owe him one of the greatest successes of quantum mechanics—his theory of the spinning electron. He showed in an ingenious way that the relativistic treatment of the electron reveals its magnetic property automatically, whereas Goudsmit and Uhlenbeck's idea of the spinning and magnetic electron had to be added from the outside to the edifice of non-relativistic quantum and wave mechanics. His further development of this theory led him to such a fantastic conception of the nature of electrons that he himself may have doubted it; and yet it obtained a wonderful verification by Anderson's discovery of the positron, the real counterpart of the negative electron.

How similar is the goal which the three men attained, but how different is the way they work! We see Heisenberg, on the one hand, always in close contact with collaborators, transferring to them his sweeping enthusiasm; on the other hand, Dirac quite alone with his thoughts and his critical logic. Schroedinger shows an attitude intermediate between the two, working mostly alone, but brought closer to his colleagues by his artistic spirit.

RUDOLF LADENBURG
EUGENE WIGNER
PRINCETON UNIVERSITY



MEMORIAL HALL TOWER FROM THE HARVARD COLLEGE YARD

THE REGISTRATION HEADQUARTERS AND THE SCIENTIFIC EXHIBITS WILL BE HELD IN MEMORIAL HALL.

THE BOSTON MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

MEMORIES of the early years of the association's history come flooding in upon us as we prepare for this winter's Boston meeting. For it was in Boston nearly one hundred years ago that the idea of the association in its present form was first proposed.

Dr. John Collins Warren, one of Boston's outstanding citizens and one of the most eminent American scientific men of his generation, had attended the seventh meeting of the British Association for the Advancement of Science held at Liverpool in September, 1837. So impressed was he with the advantages of a meeting of this kind that upon his return to Boston in August, 1838, he at once undertook to form a similar association in America.

Cooperating with him toward this end were Governor Edward Everett (later president of Harvard and Secretary of State), former Lieutenant Governor Thomas Lindall Winthrop, president of the Massachusetts Agricultural Society and of the American Antiquarian Society, and Mr. Justice Joseph Story, Dane professor of law at Harvard and a justice of the Supreme Court of the United States.

A Committee of Correspondence of the American Association was formed, and on October 30, 1839, Dr. Warren wrote a circular on the subject of the British Association and sent it to the printer, ordering fifty copies.

The American Philosophical Society in Philadelphia, as the oldest scientific society in America, was requested to take the initiative in the formation of an American Association for the Promotion of Science. To this society Dr. Warren wrote a letter, enclosing "a circular from a meeting of gentlemen at Boston."

DR. CHARLES N. MOORE
PROFESSOR OF MATHEMATICS, UNIVERSITY OF CINCINNATI; CHAIRMAN OF THE SECTION OF MATHEMATICS.

Bachrach

DR. C. J. DAVISSON
BELL TELEPHONE LABORATORIES; CHAIRMAN OF THE SECTION OF PHYSICS.

DR. ARTHUR B. LAMB

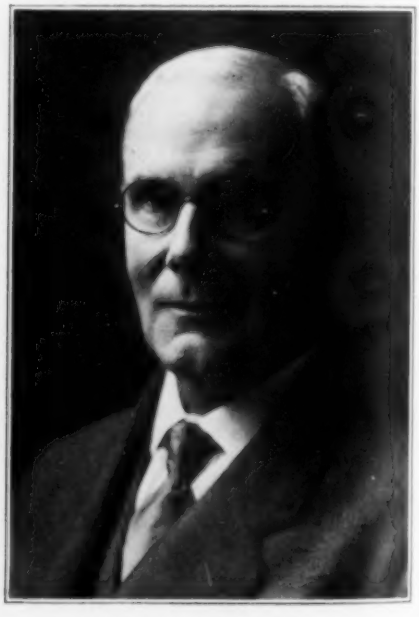
PROFESSOR OF CHEMISTRY, HARVARD UNIVERSITY; CHAIRMAN OF THE SECTION OF CHEMISTRY.

DR. R. T. CHAMBERLIN

PROFESSOR OF GEOLOGY, UNIVERSITY OF CHICAGO; CHAIRMAN OF THE SECTION OF GEOLOGY.

DR. V. M. SLIPHER

DIRECTOR OF THE LOWELL OBSERVATORY; CHAIRMAN OF THE SECTION OF ASTRONOMY.



DR. A. S. PEARSE

PROFESSOR OF ZOOLOGY, DUKE UNIVERSITY; CHAIRMAN OF THE SECTION OF ZOOLOGICAL SCIENCES.

But the society, after careful consideration of the matter, came to the conclusion that it was inexpedient to undertake the organization of such an association at that time. And so this attempt came to nothing.

Simultaneously with Dr. Warren's efforts to form an American Association for the Promotion (or Advancement—he used both words) of Science along the lines of the British Association, the Reverend Dr. Edward Hitchcock, state geologist of Massachusetts, was endeavoring to form a general association of geologists and others for the purpose of broadening the horizon of the scientific men throughout the country through the medium of friendly intercourse and discussion. Indeed, Dr. Hitchcock had begun his efforts toward this end at least a year before Dr. Warren had returned from England.

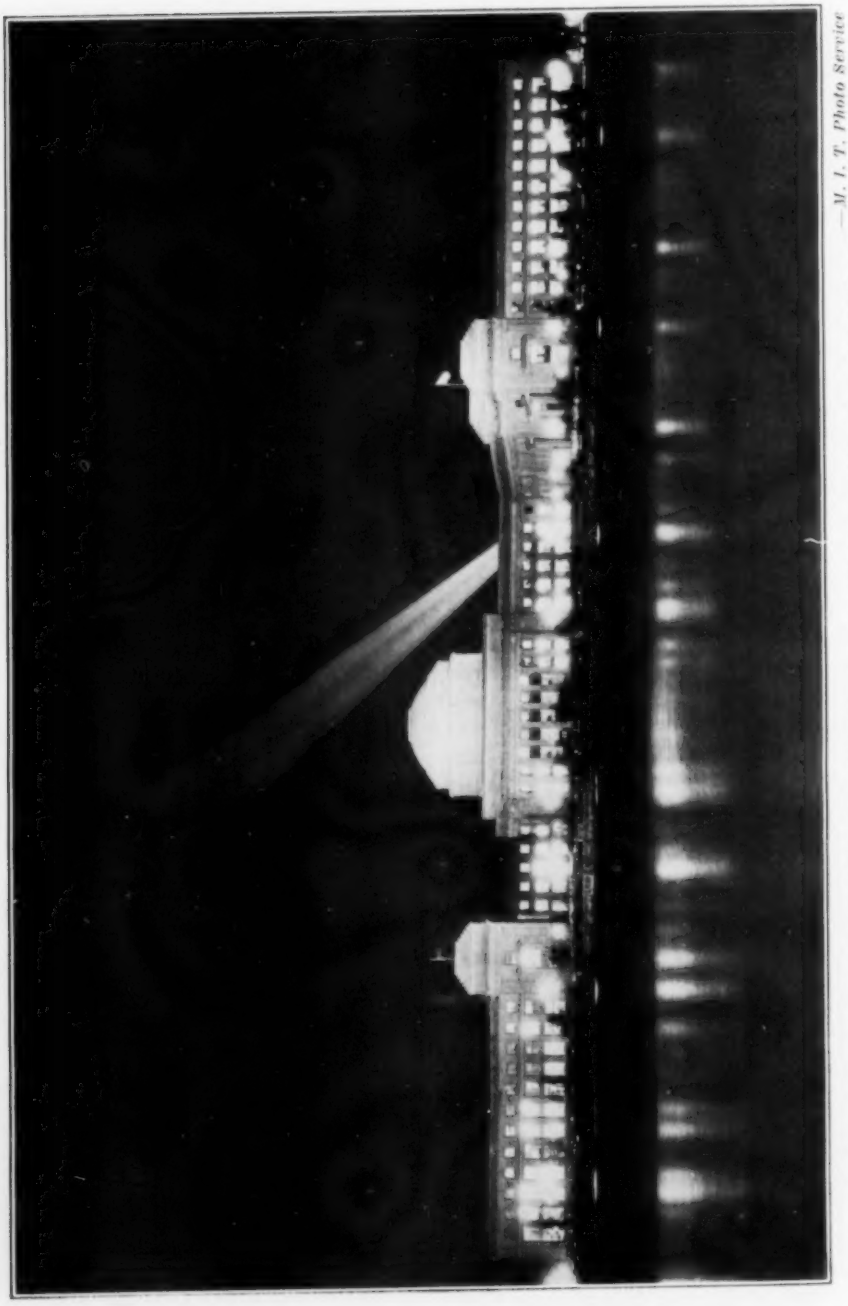
Now at that time interest in the investigation of the country's natural resources of all sorts was very great. No less than eighteen states had organized more or less elaborate and comprehensive geological surveys, of which the first three were those of North Carolina (1823), South Carolina (1824) and Massachusetts (1830), and the advantages to be gained by correlating the work of these several surveys were evident to all.

Largely as a result of Professor Hitchcock's initiative, the Association of American Geologists was organized in 1840 in Philadelphia. At the third meeting held in Boston in 1842 the name was changed to the Association of American Geologists and Naturalists. At the last meeting, which took place in Boston in 1847, the organization agreed to resolve itself into the American Association for the Promotion of Science, which at its first meeting, held in Philadelphia in 1848, changed its name to the American Association for the Advancement of Science.

In 1874 this association was incorporated under the laws of the State of Massachusetts, the articles of incorpora-

DR. K. M. WIEGAND
PROFESSOR OF BOTANY, CORNELL UNIVERSITY; CHAIRMAN OF THE SECTION OF BOTANICAL SCIENCES.

DR. WINGATE TODD
PROFESSOR OF ANATOMY, WESTERN RESERVE UNIVERSITY SCHOOL OF MEDICINE; CHAIRMAN OF THE SECTION OF ANTHROPOLOGY.



THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY AS SEEN FROM THE CHARLES RIVER AT NIGHT
—*M. I. T. Photo Service*

tion passing the House of Representatives on March 10 and the Senate on March 17, and being signed by Governor W. B. Washburn on March 19.

Massachusetts from its earliest days has always fostered literature, science and the arts. In the constitution of the state adopted on June 16, 1780, we find "... it shall be the duty of Legislatures and Magistrates, in all future periods of this Commonwealth, to cherish the interests of literature and the sciences, and all seminaries of them ... to encourage private societies and public institutions, rewards and immunities, for the promotion of agriculture, arts, sciences, commerce, trades, manufactures, and a natural history of the country. ..." Under this new constitution the American Academy of Arts and Sciences was incorporated in 1780.

Going still further back, to the time of the early settlement of New England, we find some very interesting facts.

—*Bachrach*

DR. WESLEY C. MITCHELL

PROFESSOR OF ECONOMICS, COLUMBIA UNIVERSITY; CHAIRMAN FOR THE SOCIAL AND ECONOMIC SCIENCES.

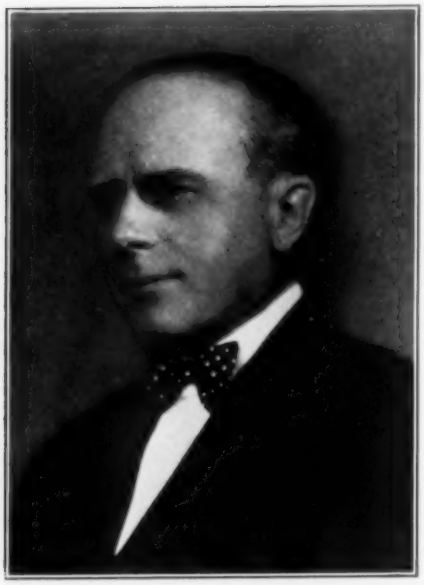
DR. W. R. MILES

PROFESSOR OF PSYCHOLOGY, YALE UNIVERSITY; CHAIRMAN OF THE SECTION OF PSYCHOLOGY.

Shortly after the first settlers had come to Massachusetts, about 1645, there existed in England an organization referred to in letters written at that time as the Invisible College. This Invisible College consisted of weekly meetings of a number of prominent men, including John Winthrop, for the purpose of discussing experimental science, a proceeding then regarded as wholly unorthodox.

In the troubled times that followed these men planned to emigrate to New England, there to establish a Society for Promoting Natural Knowledge. But immediately after the Restoration King Charles II took this organization under his protection, and it became the Royal Society.

Dr. Cromwell Mortimer wrote in 1741 that, as the proposed emigration of learned men from England to New England to form a Society for Promoting Natural Knowledge did not take place, Mr. John Winthrop first founded the



DR. WALDO G. LELAND

PERMANENT SECRETARY OF THE AMERICAN COUNCIL OF LEARNED SOCIETIES; CHAIRMAN FOR THE HISTORICAL AND PHILOLOGICAL SCIENCES.

—Cornell—Dayton, Ohio

DR. CHARLES FRANKLIN KETTERING

PRESIDENT OF THE GENERAL MOTORS RESEARCH CORPORATION; CHAIRMAN OF THE SECTION OF ENGINEERING.

College at Cambridge, in New England, since known by the name of Harvard College.

So much for the past. Bearing this in mind, let us look forward to the immediate future.

The coming meeting at Boston is the ninety-third meeting of the association. It is regarded as the fifth Boston meeting, although it will really be the sixth meeting in the Boston-Cambridge area. The association's second meeting was held in Cambridge in 1849, and the

DR. CHARLES R. STOCKARD

PROFESSOR OF ANATOMY, CORNELL UNIVERSITY MEDICAL COLLEGE; CHAIRMAN OF THE SECTION OF THE MEDICAL SCIENCES.

twenty-ninth (1880), forty-seventh (1898), sixty-first (1909–1910) and seventy-sixth (1922) meetings were held in Boston. In addition to these, the eighteenth meeting was held in Salem in 1869.

For the 1933 meeting the official headquarters will be at the Hotel Statler, in Boston, where the first general session, as well as a number of special events of importance, will be held. A large num-

ber of sections and affiliated societies will meet at this time.

The institutions welcoming the associations are Harvard University, Massachusetts Institute of Technology, Simmons College, Boston University, Boston College, Northeastern University, Tufts College, Wellesley College and Weston College. Thus the colleges and universities in the whole metropolitan area will participate as hosts to the visiting members, although for general convenience the section sessions will be held in Cambridge, in the lecture rooms at Harvard University and at the Massachusetts Institute of Technology.

The main registration headquarters will be at Memorial Hall, Harvard University, where registration facilities will be in operation from Tuesday noon, December 26, and will be maintained throughout the week. A subsidiary registration desk will be maintained in the main lobby of the central building of the Massachusetts Institute of Technology especially for the benefit of members of the engineering and other sections of which the meetings will be held at the institute.

—*Bachrach*

DR. WALTER F. DEARBORN

PROFESSOR OF EDUCATION, HARVARD UNIVERSITY; CHAIRMAN OF THE SECTION OF EDUCATION.

DR. A. R. MANN

PROVOST OF CORNELL UNIVERSITY; CHAIRMAN FOR AGRICULTURE.

Extensive commercial, college and secondary school exhibits will be displayed at Memorial Hall, Harvard University, in close proximity to the main meeting places of the various sections.

The first general session will be held at the Hotel Statler on the evening of Wednesday, December 27. After the addresses of welcome, the retiring president, Dr. John J. Abel, of the Johns Hopkins University, will speak on "Poisons and Diseases, and some Experiments with the Toxin of *Bacillus tetani*." Dr. Abel's address will be followed by a general reception.

In the afternoon of Thursday, December 28, Professor William Morris Davis will deliver the Hector Maiben lecture, speaking on "The Faith of Reverend Science." On the evening of the same

day Dr. Henry E. Sigerist, of the Johns Hopkins University, will give the Sigma Xi lecture, his title being "The Foundation of Human Anatomy in the Renaissance."

The Honorable Henry A. Wallace, Secretary of Agriculture, will give an address on "What Can Engineering Do for Agriculture?" in the evening of Friday, December 29, in the ball room of the Hotel Statler.

The Sedgwick Memorial Lecture, given under the auspices of the Biological Department of the Massachusetts Institute of Technology, will be at Huntington Hall, 491 Boylston Street, Boston, on Saturday, December 30, in the afternoon. Dr. Henry Fairfield Osborn, honorary president of the board of trustees of the American Museum of Natural History, New York, will speak on "Aristogenesis: the Creative Factor in Evolution."

The local committee is arranging a number of social events especially for the entertainment of visiting ladies, including visits to Wellesley and Radcliffe Colleges, various museums, etc.

The Boston area is too well known to require extended description. Historically, educationally and by virtue of its geographic position, it is familiar to many, if not to most, American scientists. Itself of great historic interest, its proximity to Plymouth, Salem, Lexington and Concord, as well as to other places interwoven with early colonial life and aspirations, make it a center of unusual significance to all Americans.

While Boston as a political and administrative unit is a city of approximately only 800,000 people, the thirty cities and towns of the metropolitan area, all within a radius of fifteen miles, make the real or "greater" Boston the fourth city of the United States in population, with about 2,250,000 people. The commercial significance of Boston, based upon the essential industries of wool, cotton, boots and shoes, machinery, etc., is well known.

Its beautiful park system, excellent harbor, ease of access to mountains, diversified seashores and charming rural districts need only be mentioned. To those who will attend the Boston meeting this year under winter conditions, its significance as an educational and scientific center will perhaps be the chief item of importance, for Boston is the greatest educational center of the western world, including within its limits, or within a radius of fifty miles, not only the institutions which will act as hosts on this occasion, but numerous other colleges, schools of music and art, preparatory and vocational schools. The personnel and student bodies of these institutions would in themselves make up a city of many tens of thousands.

Among the places of interest in Boston and Cambridge may be mentioned the Peabody Museum, the Germanic Museum, the Museum of Comparative Zoology, the Fogg Art Museum, the Astronomical Observatory and the Botanic Gardens, at Harvard; the Nautical Museum of the Massachusetts Institute of Technology; the Boston Art Museum, Gardner Museum, Boston Public Library, Boston Society of Natural History, State House (historical collections), Old State House, Watertown Arsenal, Charlestown Navy Yard, Bunker Hill, Old South Church, Paul Revere House, etc. An illustrated booklet descriptive of Boston and its environs will be supplied to each registrant at the meeting through the courtesy of the Boston Chamber of Commerce.

Respect for the past and for the achievements of our predecessors is a necessary basis for a sound and well-reasoned approach to the problems of the present and the future. But respect for the past does not imply stagnation. No better illustration of this fact can anywhere be found than in the development of the scientific, cultural and educational organizations and institutions in and about Boston.

AUSTIN H. and LEILA F. CLARK